



US009151819B2

(12) **United States Patent**
Bonnefoy et al.

(10) **Patent No.:** **US 9,151,819 B2**
(45) **Date of Patent:** **Oct. 6, 2015**

(54) **ANTENNA APPARATUS FOR DETERMINING THE POSITION OF A RADIO-FREQUENCY TRANSPONDER**

(75) Inventors: **Pierre Bonnefoy**, Aix en provence (FR);
Benjamin Limongi, Aix en provence (FR)

(73) Assignee: **PSION INC.**, Mississauga, Ontario (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 326 days.

(21) Appl. No.: **13/179,237**

(22) Filed: **Jul. 8, 2011**

(65) **Prior Publication Data**

US 2013/0009820 A1 Jan. 10, 2013

(51) **Int. Cl.**
G01S 3/10 (2006.01)
H01Q 1/22 (2006.01)
H01Q 21/00 (2006.01)
G01S 3/40 (2006.01)

(52) **U.S. Cl.**
CPC **G01S 3/40** (2013.01); **H01Q 1/2208** (2013.01); **H01Q 21/00** (2013.01)

(58) **Field of Classification Search**
USPC 342/368, 417
IPC G01S 3/40
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,871,476 A * 1/1959 Busignies 342/441
3,328,794 A * 6/1967 Baltzer 342/62
3,733,603 A * 5/1973 Johnston 342/192

4,219,821 A * 8/1980 Selim 342/445
4,656,480 A * 4/1987 Allezard et al. 342/151
4,823,138 A * 4/1989 Shibano et al. 342/457
4,833,481 A * 5/1989 Shibano et al. 342/457
5,280,293 A * 1/1994 Tong 342/417
2004/0038713 A1 * 2/2004 Okawa et al. 455/561
2004/0235497 A1 * 11/2004 Zekavat 455/456.1
2008/0252524 A1 * 10/2008 Chu et al. 342/375
2009/0173820 A1 * 7/2009 Bock 244/3.15
2009/0232023 A1 * 9/2009 Soffer et al. 370/254
2009/0315759 A1 * 12/2009 Mak et al. 342/147
2010/0127875 A1 * 5/2010 Wong 340/572.7
2011/0068980 A1 * 3/2011 Vered et al. 342/432
2012/0258741 A1 * 10/2012 Tillson et al. 455/457

OTHER PUBLICATIONS

Minimum (plural minima). (2008). In The Penguin Dictionary of Mathematics. Retrieved from http://www.credoreference.com/entry/penguinmath/minimum_plural_minima.
E.W. Weisstein, "Minimum." Wolfram MathWorld, <http://mathworld.wolfram.com/Minimum.html>, accessed Sep. 20, 2013.*

(Continued)

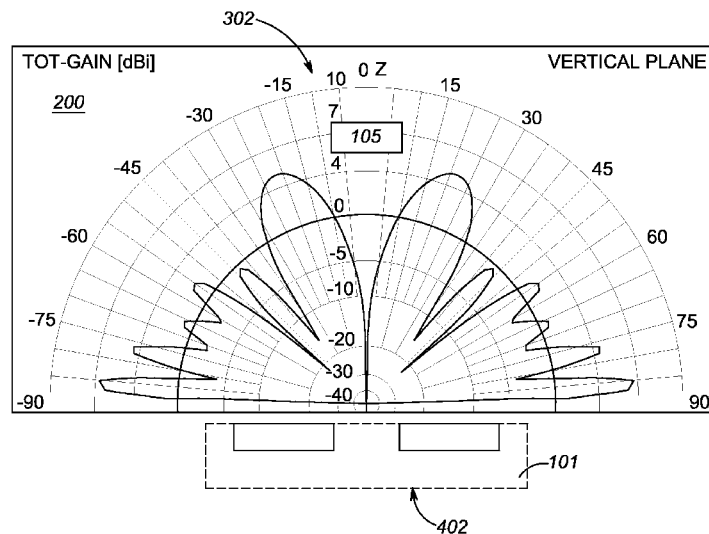
Primary Examiner — Tashiana Adams

Assistant Examiner — Fred H Mull

(57) **ABSTRACT**

An antenna apparatus for determining the position of a radio-frequency transponder is provided, comprising a phased array of antennas enabled to transmit and receive power at a given frequency for communicating with a radio frequency (RF) transponder, the phased array being movable; and a phase shifter for providing a phase shift to at least one antenna of the phased array to provide a minima in a main radiated lobe of the phased array, such that when the phased array is moved from a first position, for detecting the RF transponder via the main radiated lobe, to a second position, where a signal from the RF transponder is minimized, a position of the RF transponder determined to be along an axis of the minima in the second position.

16 Claims, 21 Drawing Sheets



(56)

References Cited

OTHER PUBLICATIONS

M.L. Burrows, Closer Spacing of Geostationary Satellites through Adaptive Nulling at the Ground Terminal, IEEE Transactions on Antennas and Propagation, vol. 35(7), p. 870-873, Jul. 1987.*
 Communication. (2001). In Hargrave's communications dictionary, Wiley. Retrieved from <http://search.credoreference.com/content/entry/hargravecomms/communication/0>.
 Main lobe. (2001). In Hargrave's communications dictionary, Wiley. Retrieved from http://search.credoreference.com/content/entry/hargravecomms/main_lobe/0.*

D.M. Dobkin, The RF in RFID: Physical layer operation of passive UHF tags and readers, http://www.enigmatic-consulting.com/Communications_articles/RFID/RFID_frequencies.html, Oct. 2005.*
 Ultra high frequency (UHF). (1999). In Focal dictionary of telecommunications, focal press. Retrieved from http://search.credoreference.com/content/entry/bhfidt/ultra_high_frequency_uhf/0.
 Indicate. (2011). The American Heritage Dictionary of the English Language. Boston, MA: Houghton Mifflin. Retrieved from <http://search.credoreference.com/content/entry/hmdictenglang/indicate/0>.*

* cited by examiner

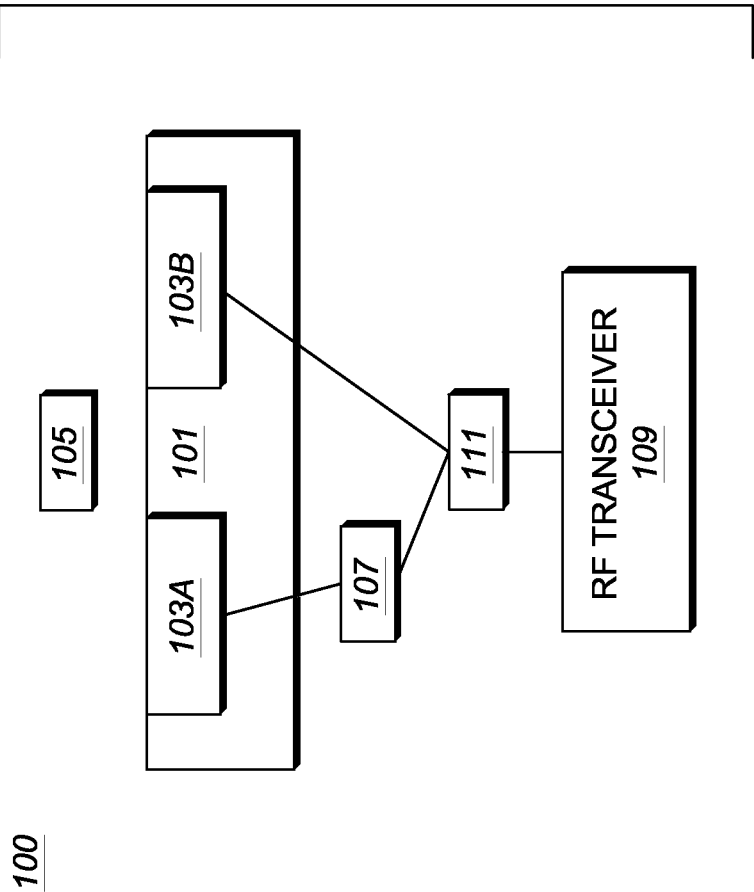


FIG. 1

200

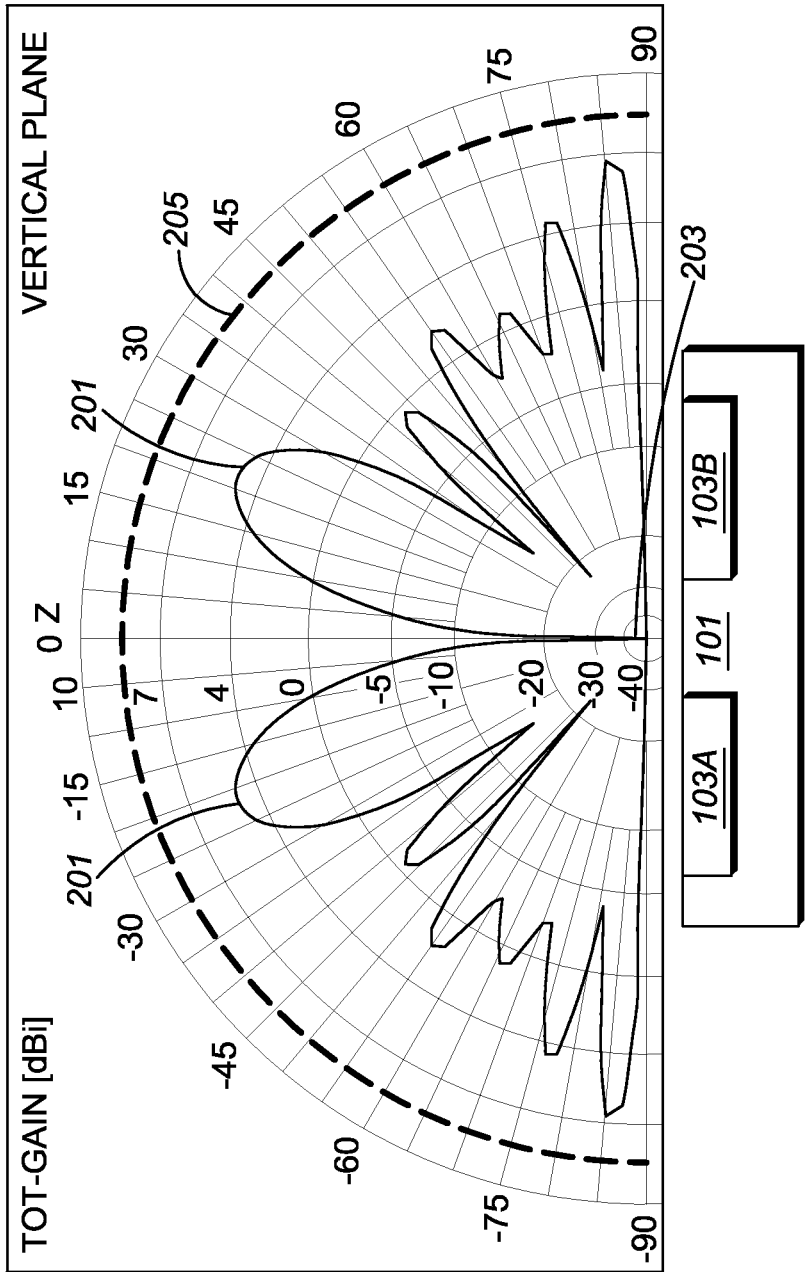


FIG. 2

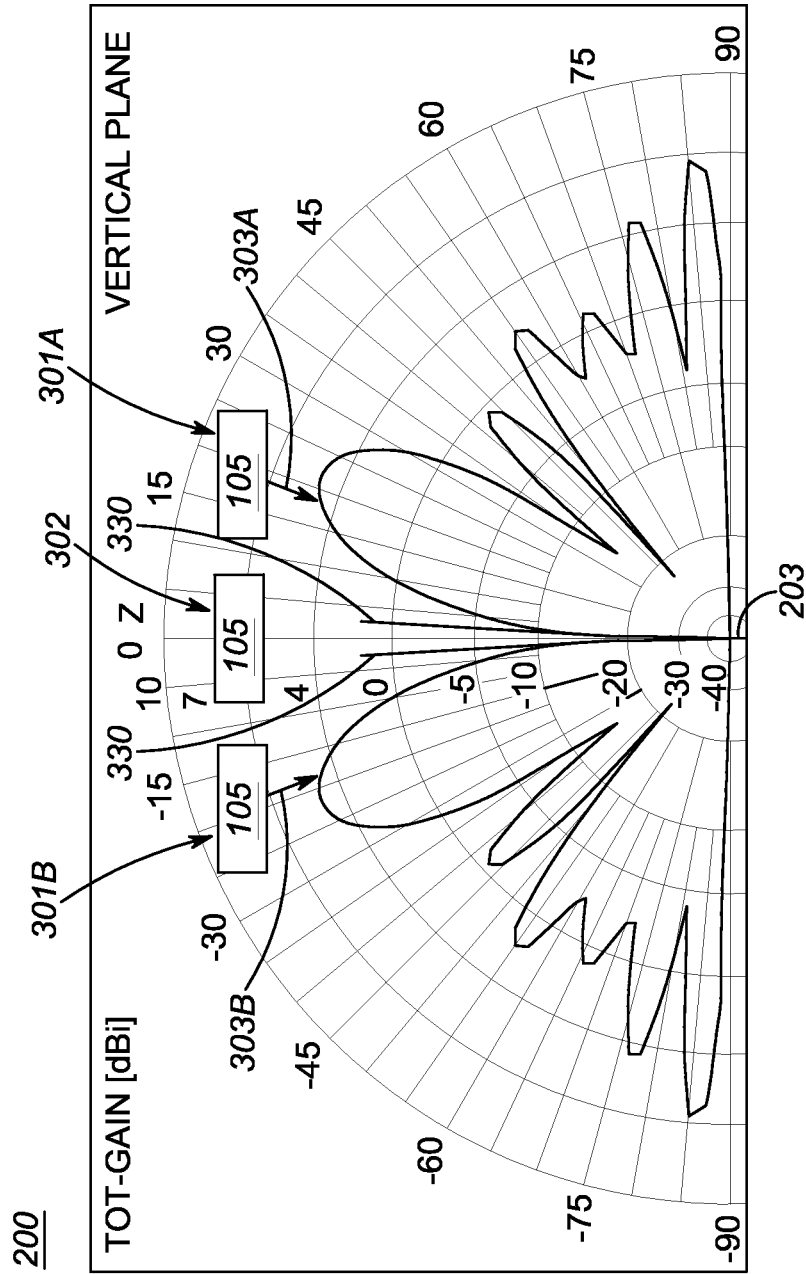


FIG. 3

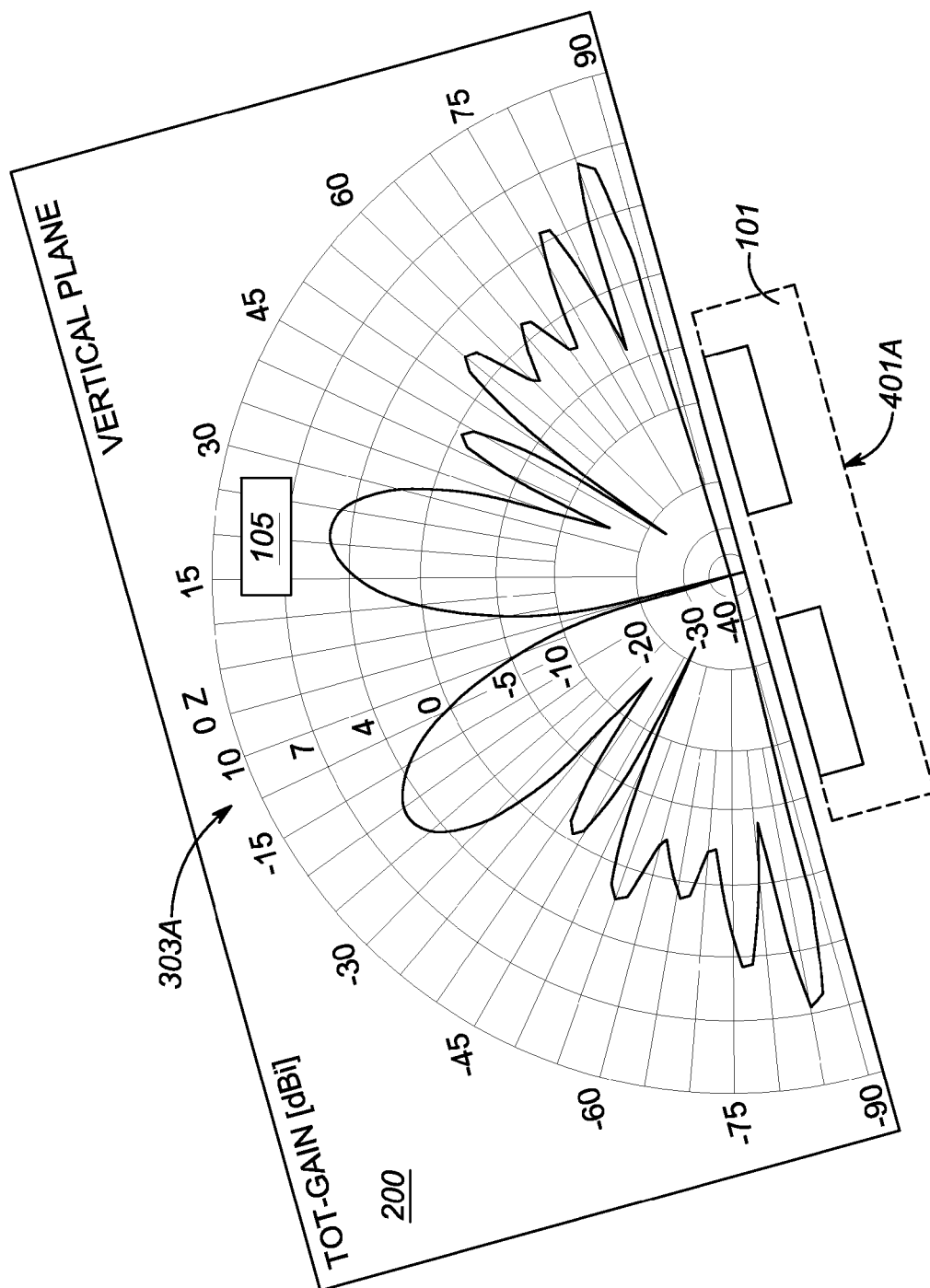


FIG. 4A

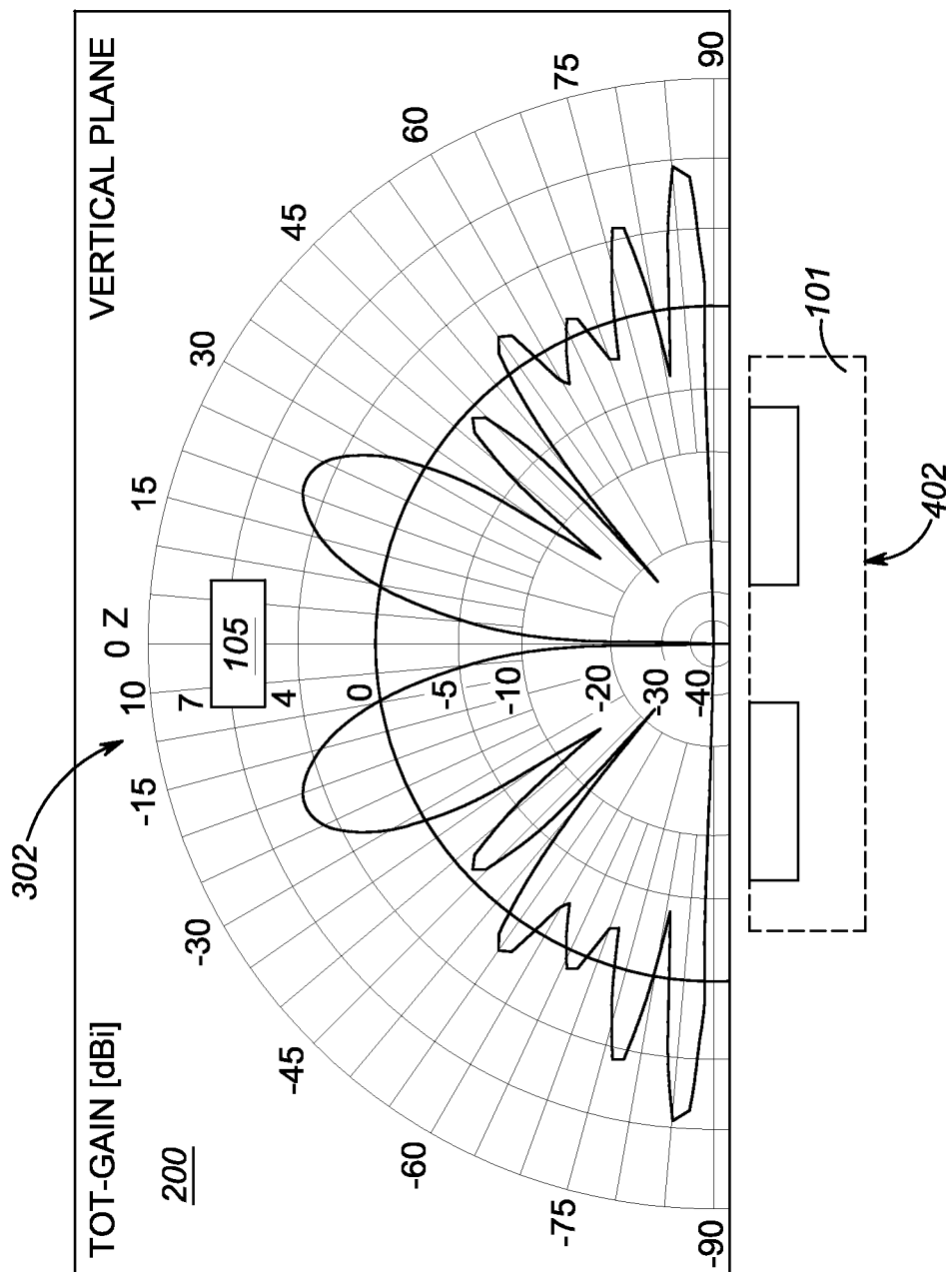


FIG. 4B

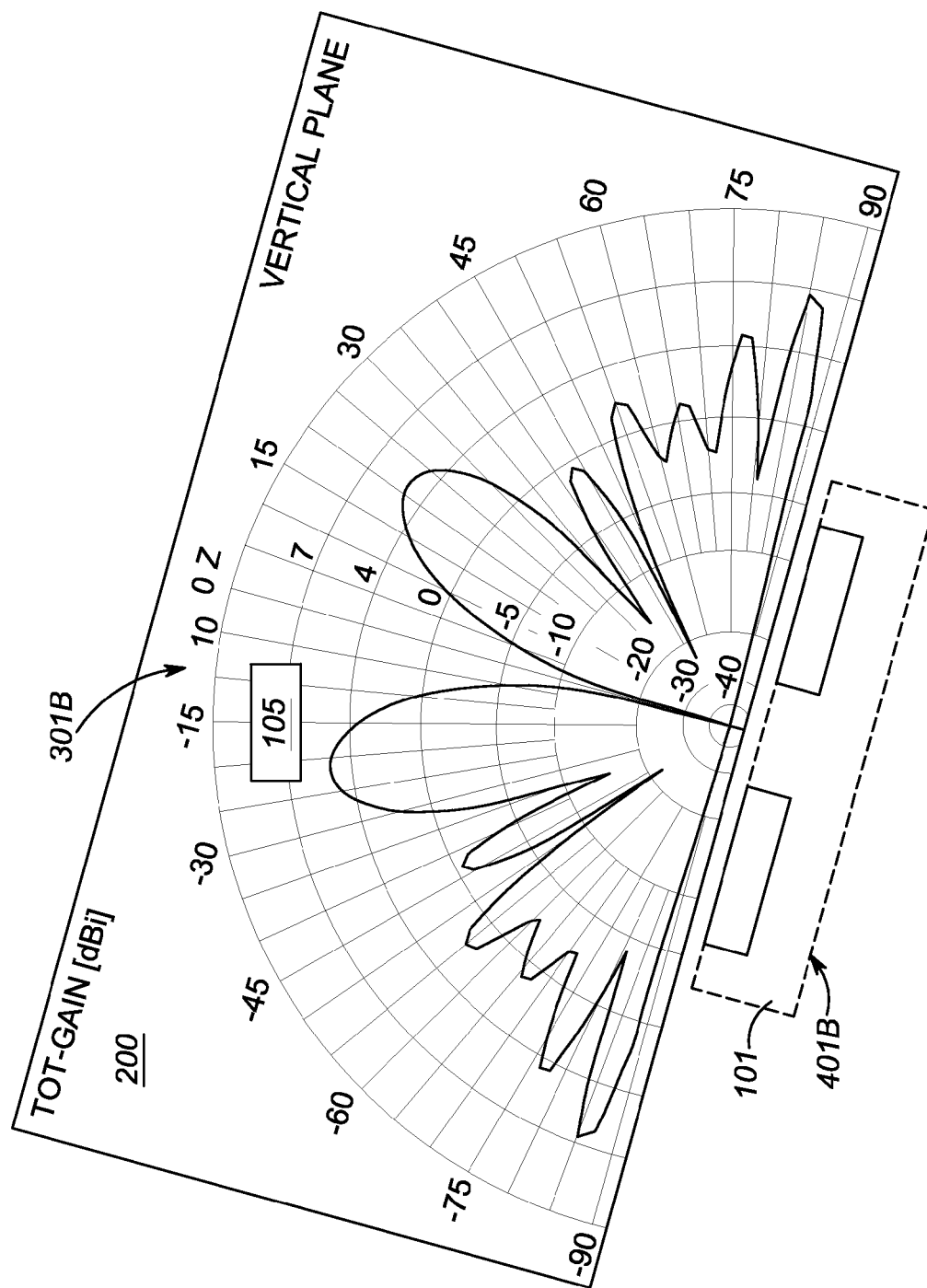
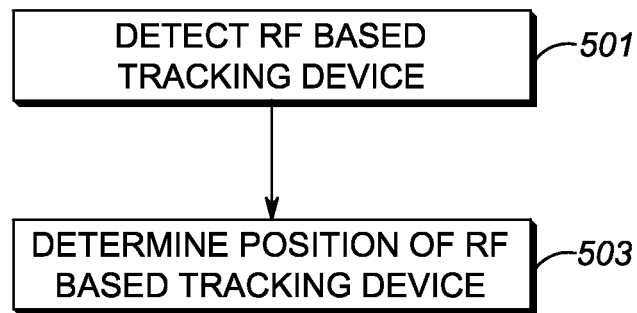


FIG. 4C

500*FIG. 5*

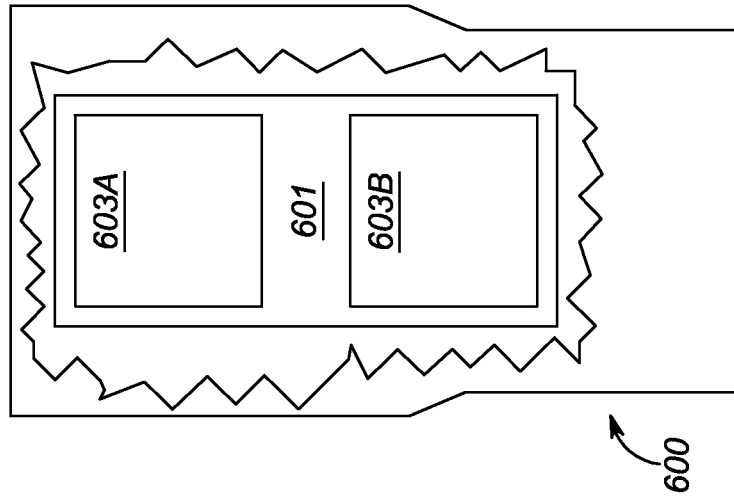


FIG. 6B

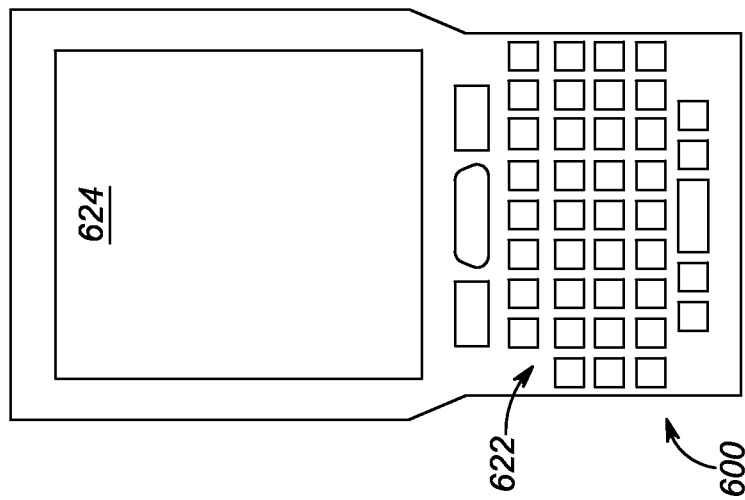


FIG. 6A

600

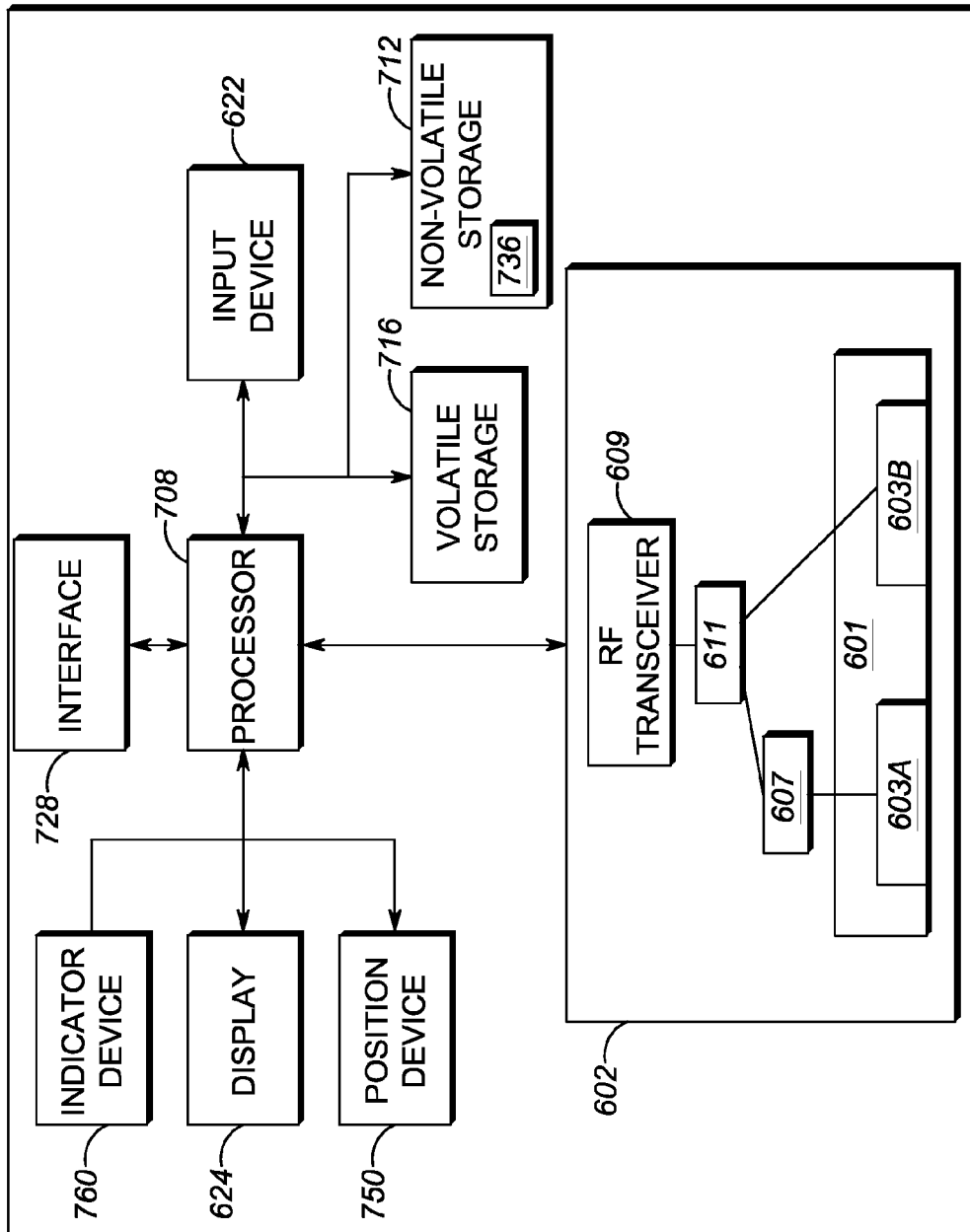


FIG. 7

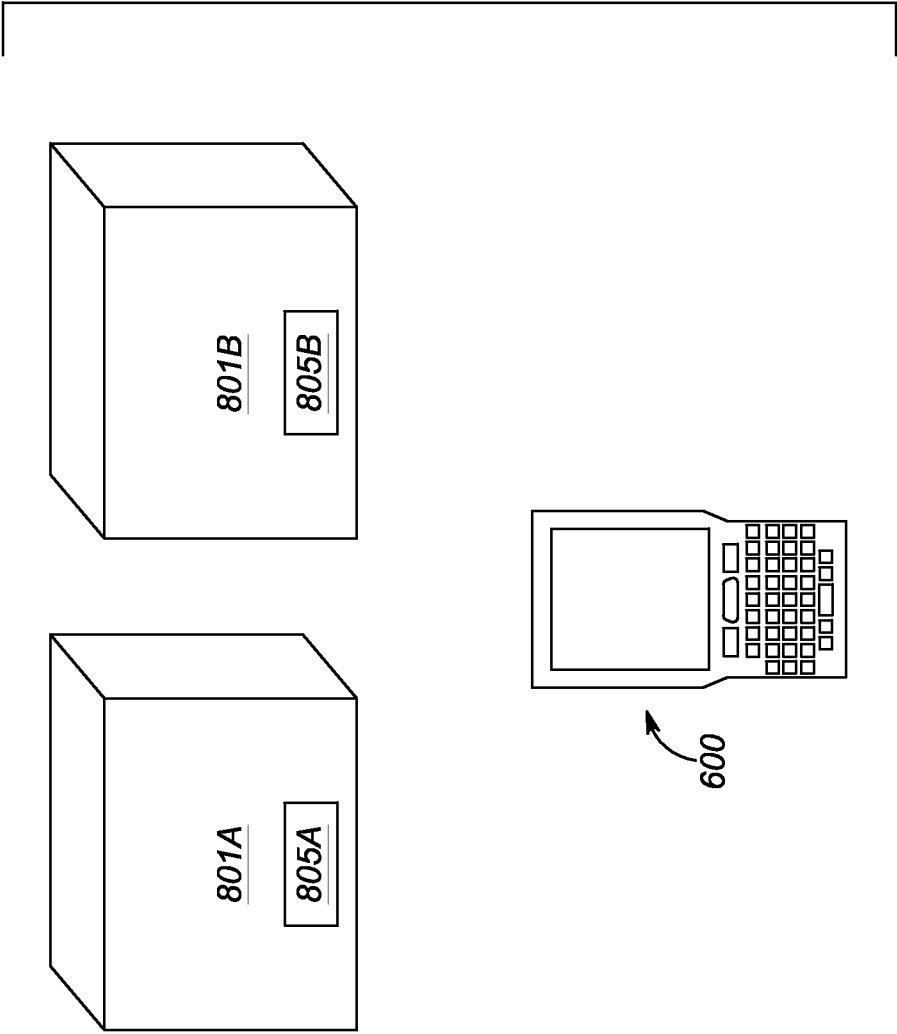


FIG. 8

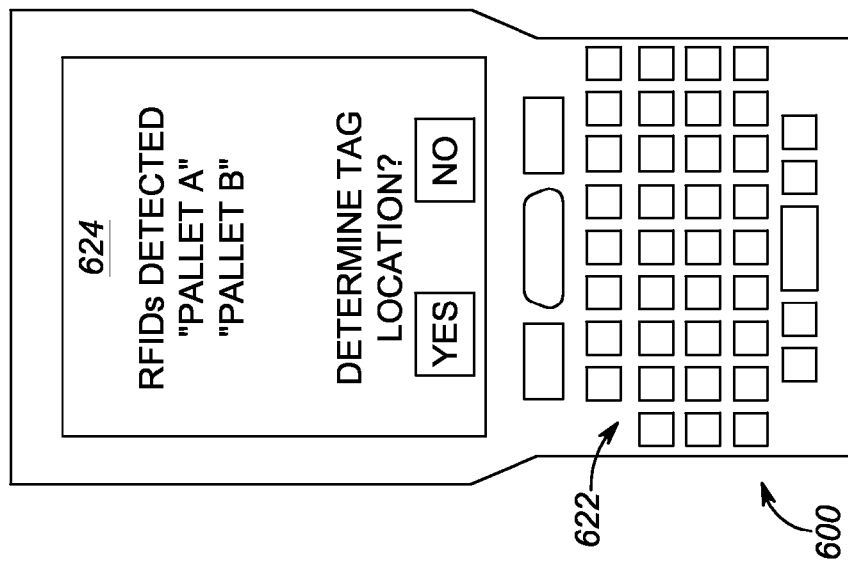


FIG. 9A

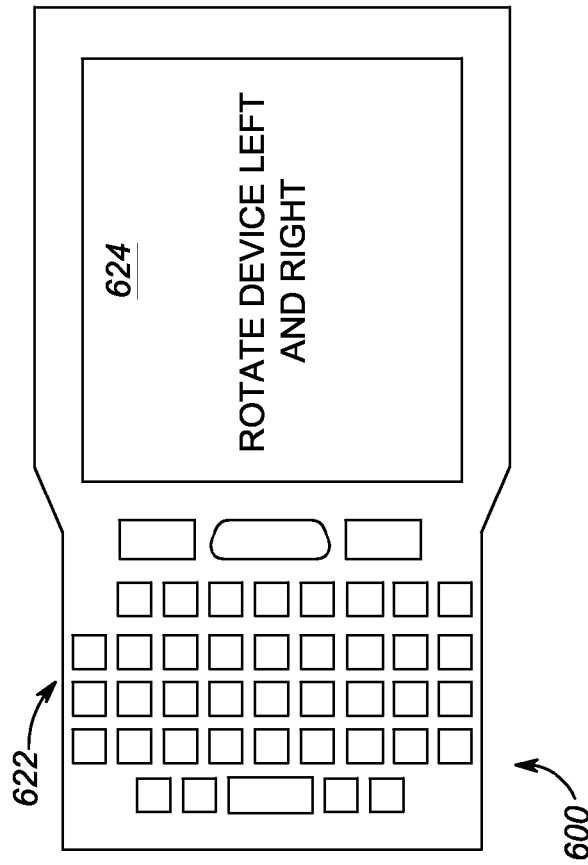


FIG. 9B

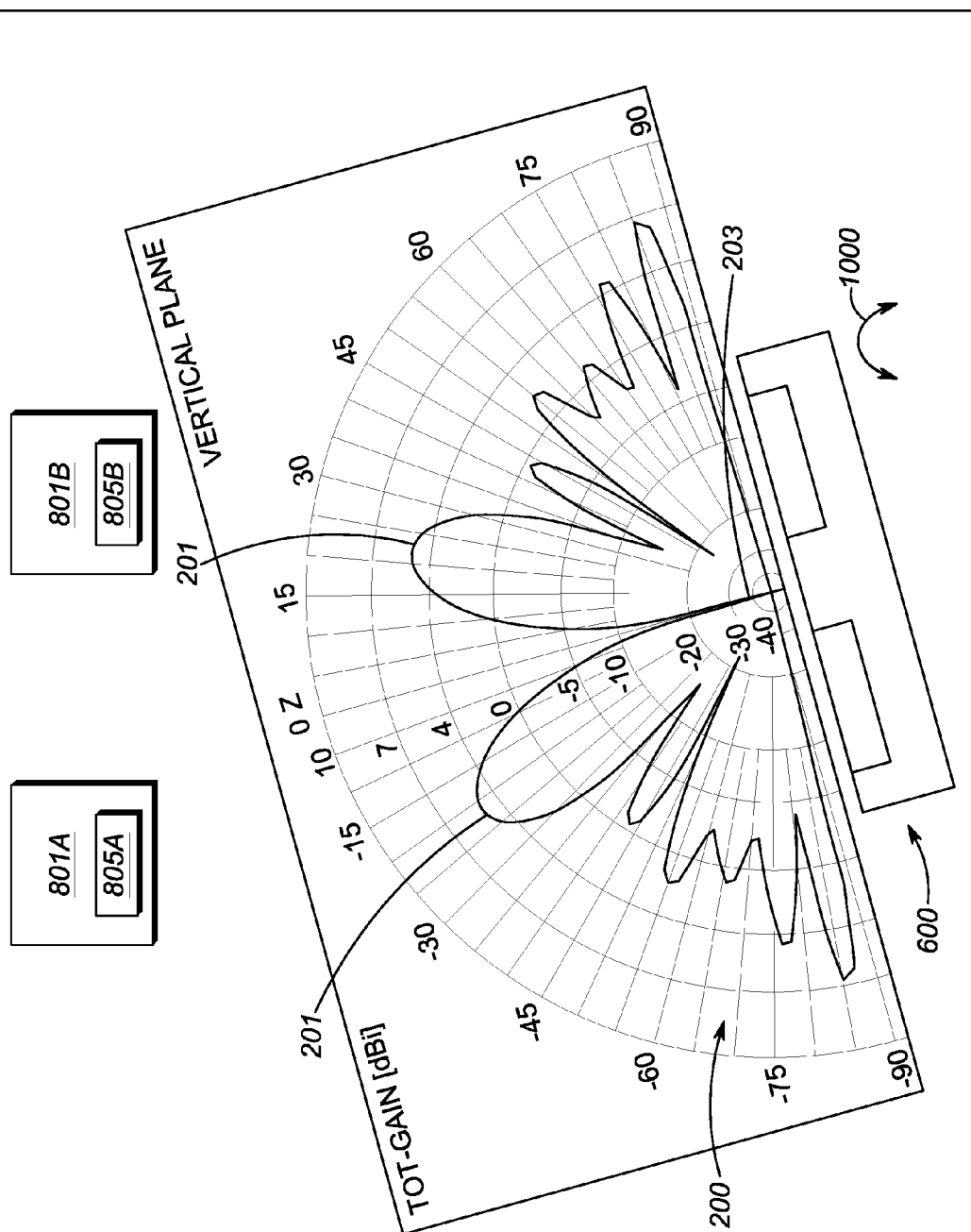


FIG. 10

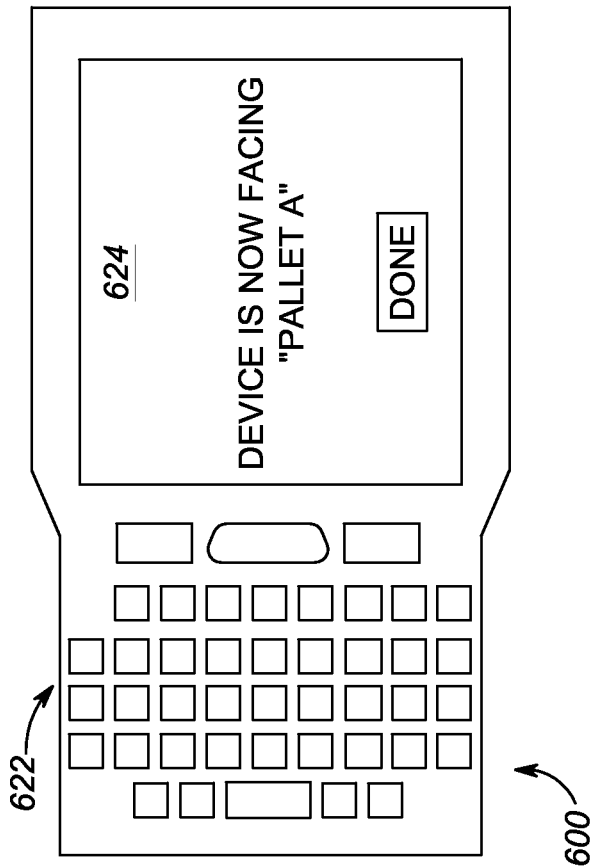


FIG. 11

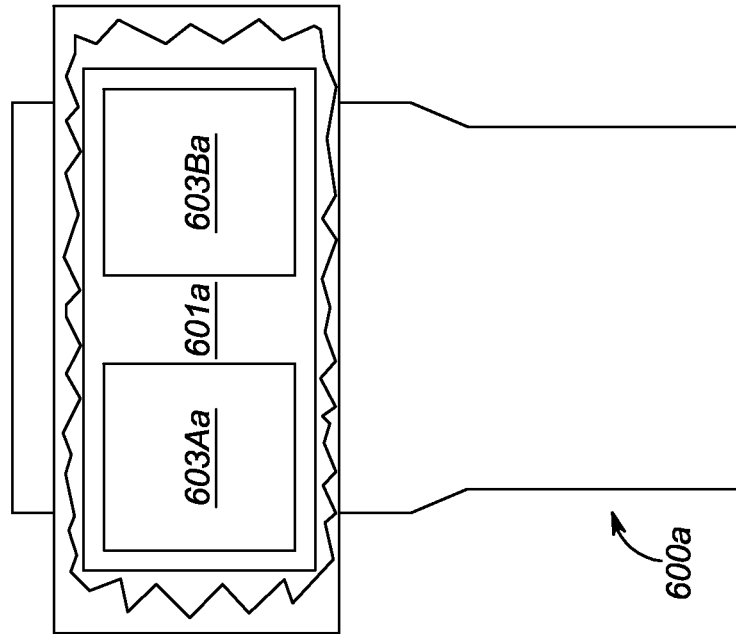


FIG. 12B

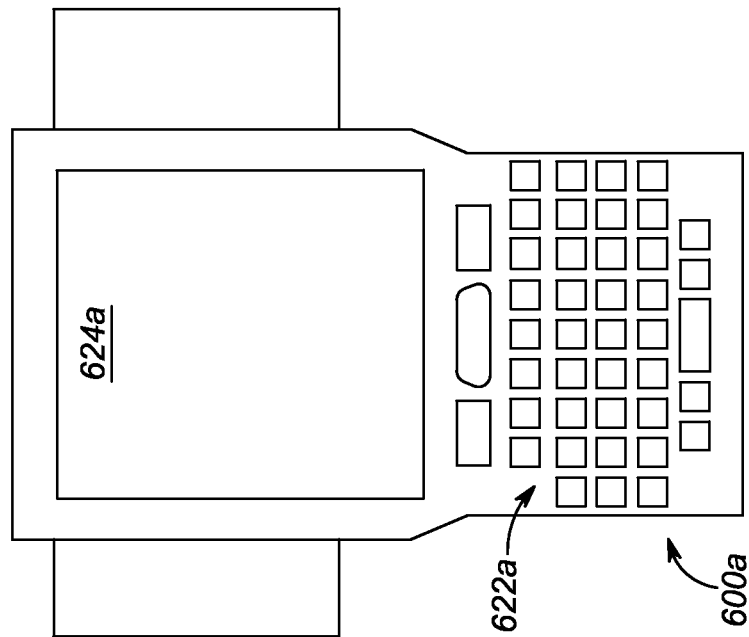


FIG. 12A

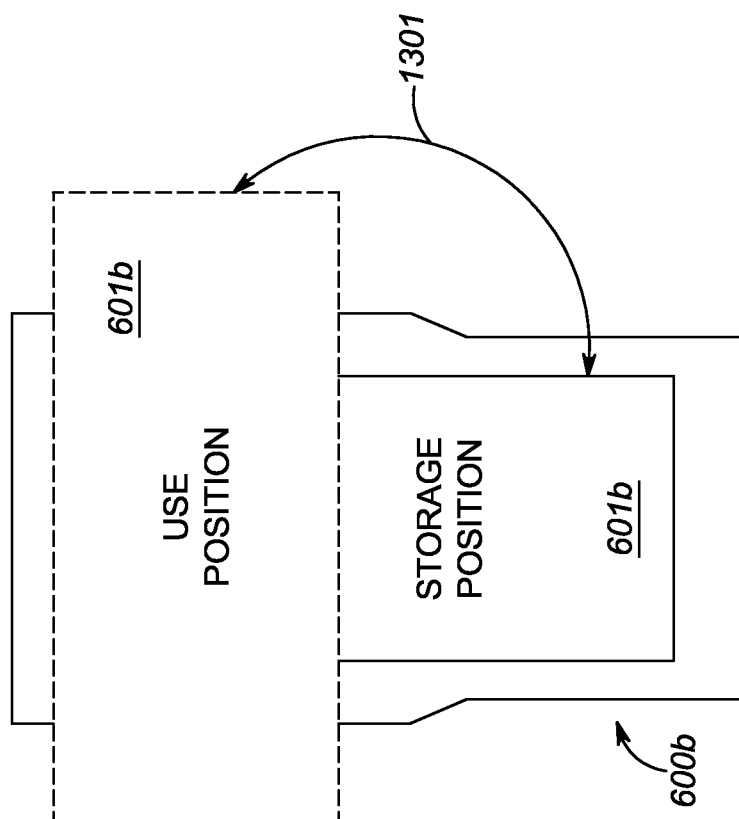


FIG. 13

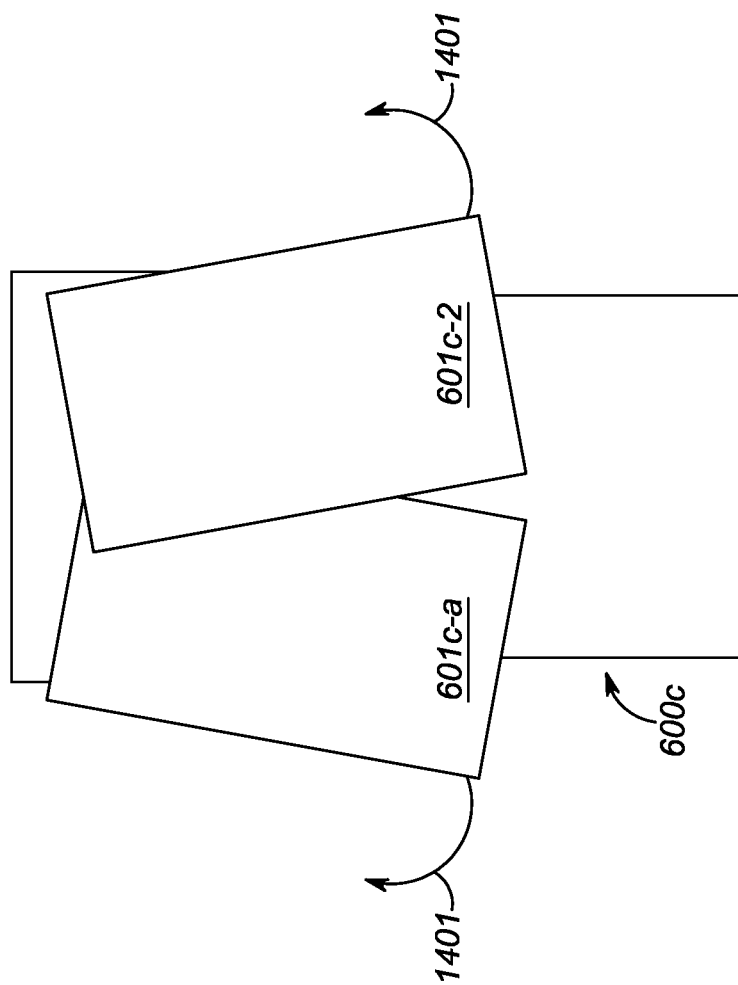


FIG. 14

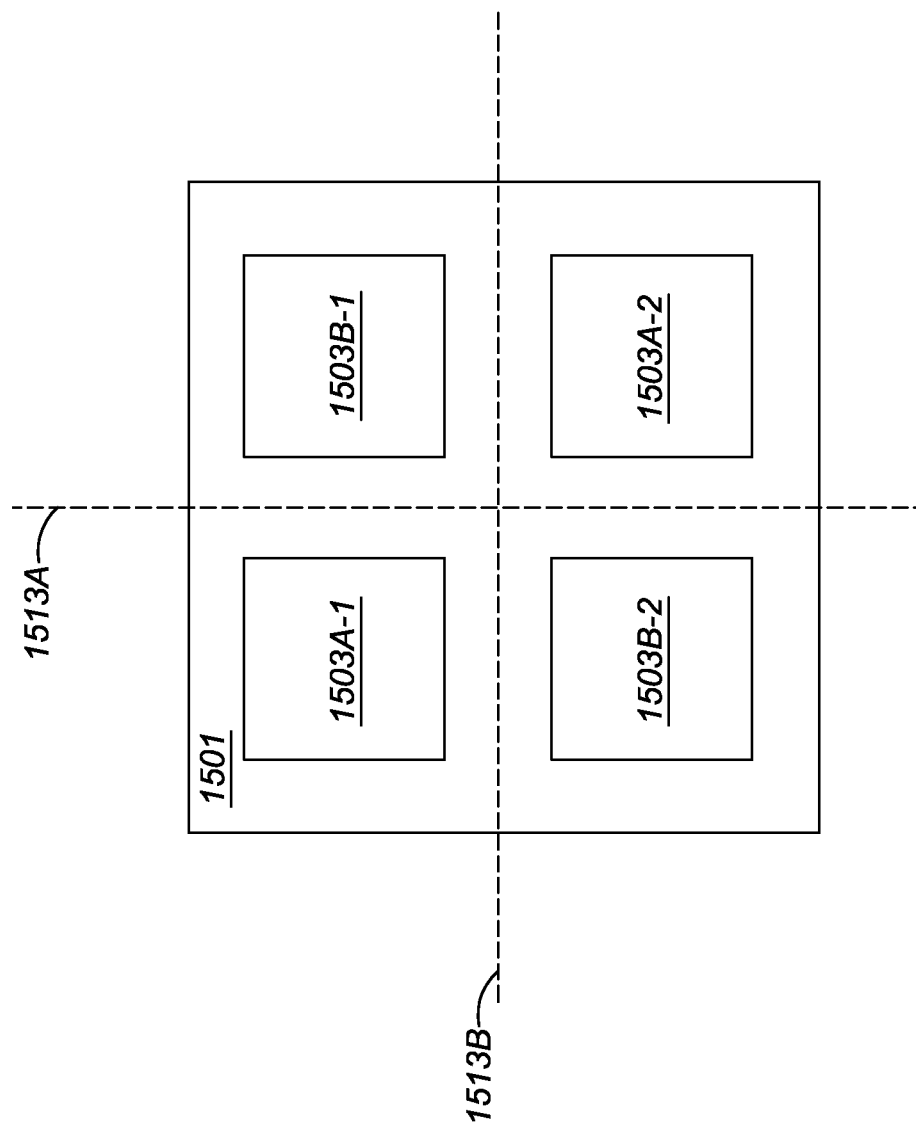


FIG. 15

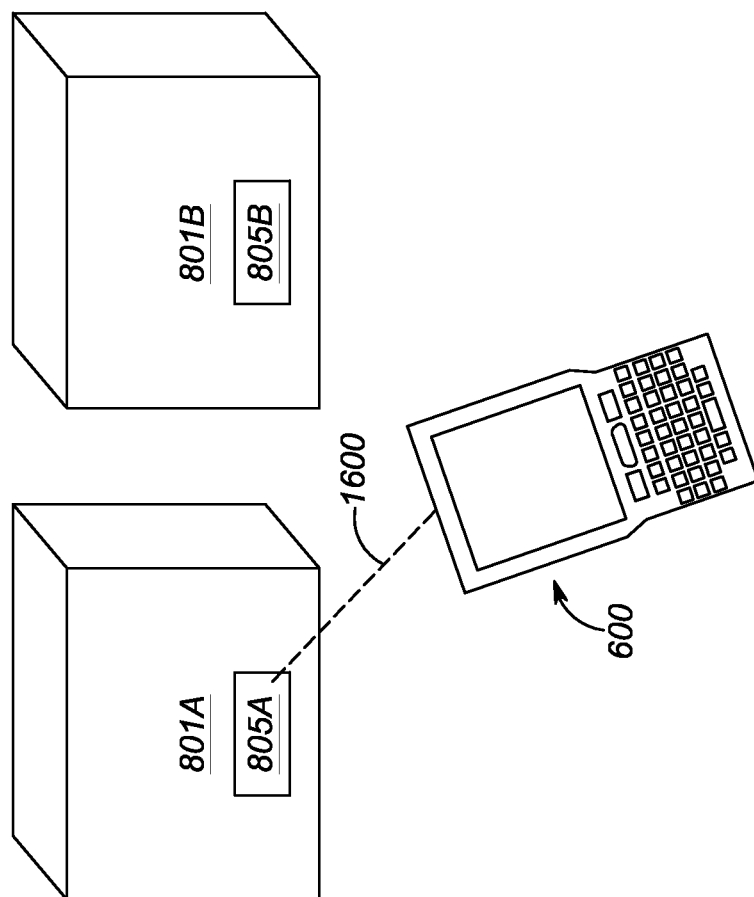


FIG. 16

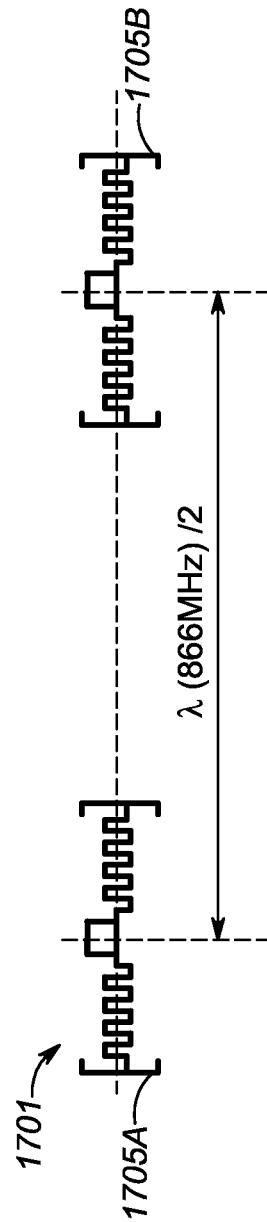


FIG. 17

1800

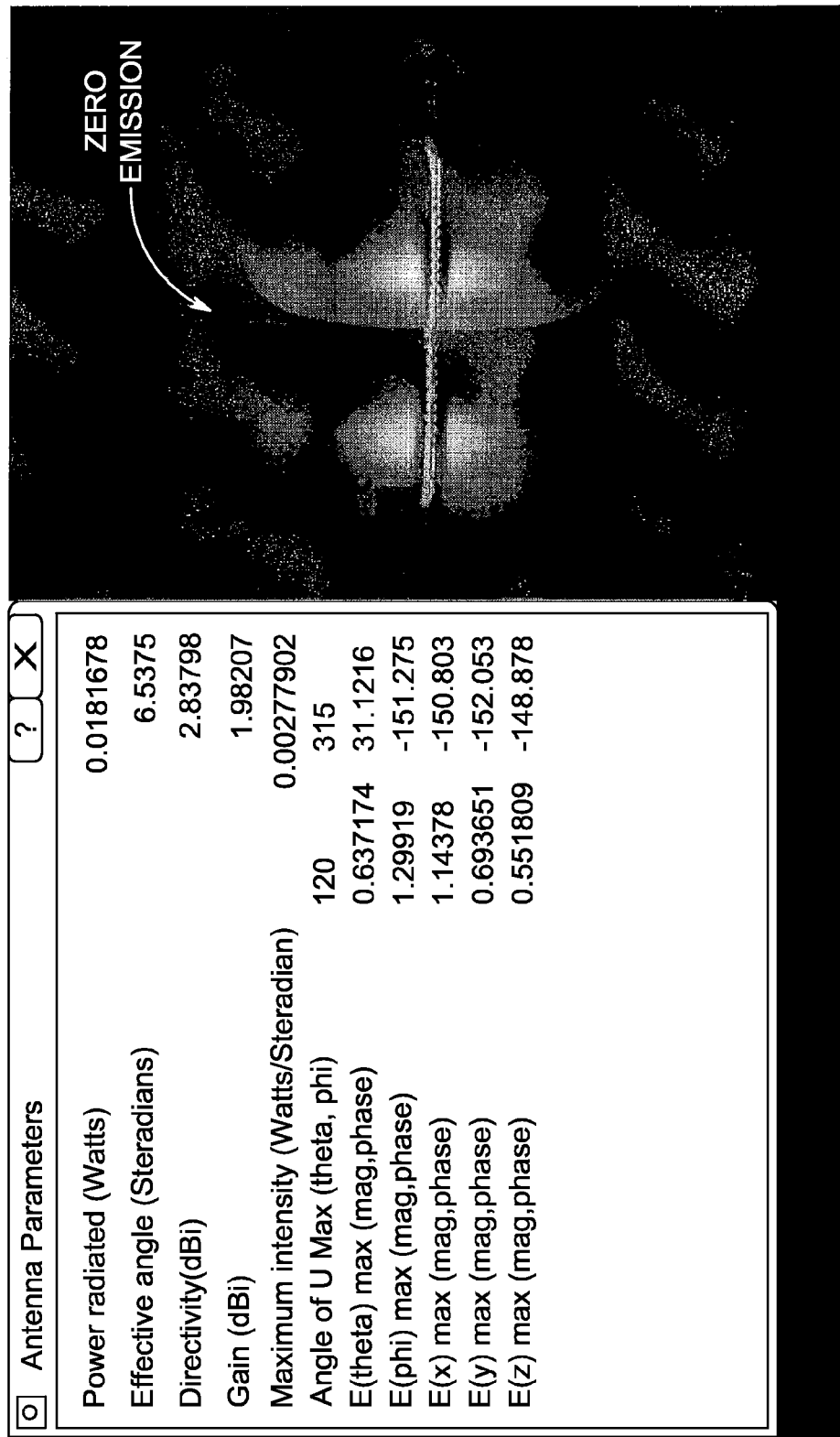


FIG. 18

1900

m1	Phi=129.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-1.846$
m3	Phi=108.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-4.963$
m5	Phi=102.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-7.963$
m7	Phi=99.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-10.302$
m9	Phi=96.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-13.744$
m11	Phi=93.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-19.850$

m2	Phi=51.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-1.886$
m4	Phi=72.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-4.902$
m6	Phi=78.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-7.837$
m8	Phi=81.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-10.110$
m10	Phi=84.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-13.437$
m12	Phi=87.000 $10 \cdot \log_{10}(\text{mag}(\text{Gain}))=-19.214$

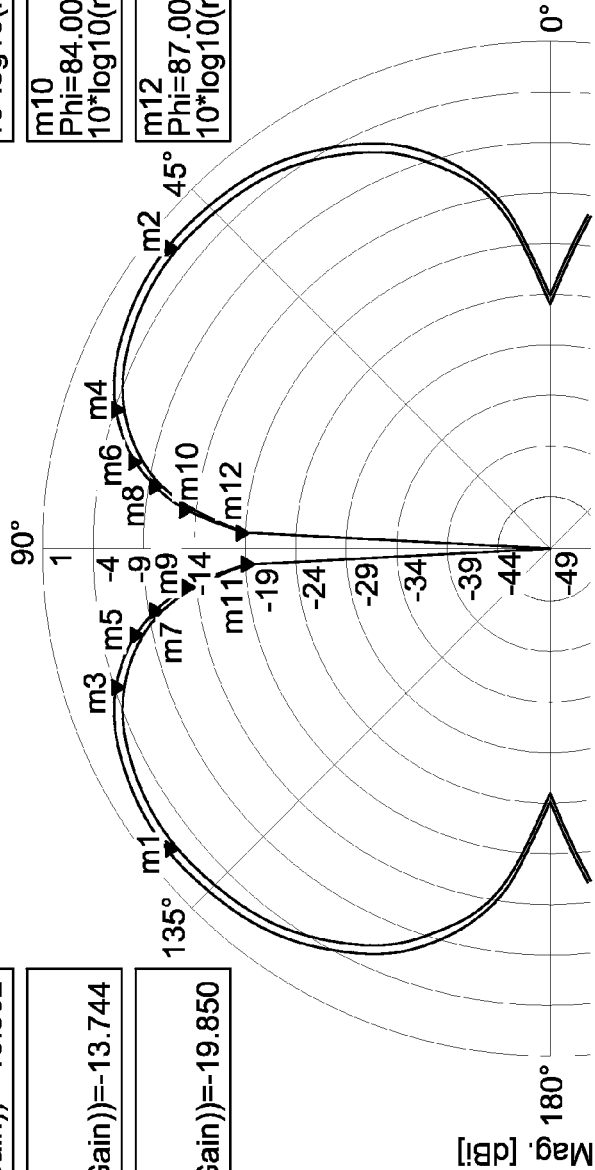


FIG. 19

1

ANTENNA APPARATUS FOR DETERMINING THE POSITION OF A RADIO-FREQUENCY TRANSPONDER

FIELD

The specification relates generally to phased array antennas, and specifically to an antenna apparatus for determining the position of a radio-frequency transponder.

BACKGROUND

Information from radio-frequency (RF) transponders, such as RFID tags, are detected and read using antennas. However, antenna radiation patterns tend to be uniform such that the position of detected RF transponders is ambiguous. For example, RFID detectors simply read any RFID tags within a given range, but there is no directivity information, because the antenna radiated pattern of an RFID detector is large. Hence, for example, when an RFID detector detects an RFID tag, there is no information provided on where the RFID tag might be located. Hence, in warehousing situations for example, an operator trying to locate a given RFID tag (e.g. attached to a pallet), currently is provided with no indication as to where the given RFID might be located, which is highly inconvenient when trying to locate items.

SUMMARY

An aspect of the specification provides an antenna apparatus comprising: a phased array of antennas enabled to transmit and receive power at a given frequency for communicating with a radio frequency (RF) transponder, the phased array being movable; and, a phase shifter for providing a phase shift to at least one antenna of the phased array to provide a minima in a main radiated lobe of the phased array, such that when the phased array is moved from a first position, for detecting the RF transponder via the main radiated lobe, to a second position, where a signal from the RF transponder is minimized, a position of the RF transponder determined to be along an axis of the minima in the second position.

The minima can comprise a null and no response is received from the RF transponder when the RF transponder is located along the axis of the minima in the second position.

The phase shift can be approximately 180°. The phased array can comprise a first pair of antennas, wherein the centers thereof are separated by approximately half of a wavelength associated with the given frequency. The phased array can further comprise a second pair of antennas laterally displaced from the first pair, one antenna of the second pair enabled to be out of phase with the remaining antenna of the second pair providing a second minima in the main radiated lobe perpendicular to the minima such that the RF transponder can be located in at least two spatial dimensions.

The antenna apparatus can further comprise: at least at least one RF transceiver for powering the phased array. The at least one RF transceiver can be common to all antennas of the phased array; the antenna apparatus can further comprise a power splitter for splitting power from the at least one RF transceiver to all the antennas of the phased array.

The antenna apparatus can further comprise a processor for determining when the signal from the RF transponder is minimized, and in response providing an indication of the location of the RF transponder. Providing the indication of the location of the RF transponder can comprise at least one of: rendering visual indicator at a display to indicate the location; controlling a speaker to provide an aural indicator to indicate the

2

location; controlling a light to indicate the location; controlling a haptic device to indicate the location; and, controlling a laser device to indicate the location.

The phase shifter can be configured to be enabled and disabled such that the minima can be turned on and off, and such that the RF transponder can be detected in the first position with the phase shifter disabled and the minima removed, and the position of the RF transponder determined in the second position with the phase shifter enabled and the minima turned on.

For detecting the RF transponder in the first position, a given antenna of the phased array can be enabled to be on while remaining antennas are enabled to be off in the first position, thereby turning the minima off, and in the second position, the remaining antennas can be further enabled to be on, with the at least one antenna phase shifted, thereby turning the minima on.

The antenna apparatus can further comprise a handheld device for providing data received in the signal from the RF transponder and providing an indication of the position of the RF transponder at a display, the phased array integrated with the handheld device.

The given frequency can be in at least one of a range of 300 MHz and 100 GHz, and a range of 800 MHz to 950 MHz.

Another aspect of the specification provides a method comprising: detecting an RF transponder via a main radiated lobe of a phased array of antennas in a first position, the phased array enabled to transmit and receive power at a given UHF (ultra high frequency) frequency for communicating with the RFID (radio frequency identification) tag, the phased array being moveable; and, determining a position of the RF transponder when the phased array is moved to a second position where a signal from the RF transponder is minimized, at least one antenna of the phased array phase shifted using a phase shifter to provide a minima in the main radiated lobe, the position of the RF transponder determined to be along an axis of the minima in the second position.

The method can further comprise providing an indication of the position of the RF transponder. Providing the indication of the location of the RF transponder can comprise at least one of: rendering visual indicator at a display to indicate the location; controlling a speaker to provide an aural indicator to indicate the location; controlling a light to indicate the location; controlling a haptic device to indicate the location; and, controlling a laser device to indicate the location.

The phase shifter can be configured to be enabled and disabled such that the minima can be turned on and off; and the method can further comprise detecting the RF transponder in the first position with the phase shifter disabled and the, minima removed, and determining the position of the RF transponder in the second position with the phase shifter enabled and the minima turned on.

For detecting the RF transponder in the first position, a given antenna of the phased array can be enabled to be on while remaining antennas are enabled to be off in the first position, thereby turning the minima off, and in the second position, the remaining antennas can be further enabled to be on, with the at least one antenna phase shifted, thereby turning the minima on.

Yet another aspect of the specification provides a computing device comprising: a phased array of antennas enabled to transmit and receive power at a given frequency for communicating with a radio frequency (RF) based-tracking device, the phased array being movable; a phase shifter for providing a phase shift to at least one antenna of the phased array to provide a minima in a main radiated lobe of the phased array; and a processing unit enabled to: detect the RF transponder

3

via the main radiated lobe of the phased array of antennas in a first position; and determine a position of the RF transponder when the phased array is moved to a second position where a signal from the RF transponder is minimized, the position of the RF transponder determined to be along an axis of the minima in the second position.

Another aspect of the specification provides a computer program product, comprising a computer usable medium having a computer readable program code adapted to be executed to implement a method comprising: a phased array of antennas enabled to transmit and receive power at a given frequency for communicating with a radio frequency (RF) transponder, the phased array being movable; and, a phase shifter for providing a phase shift to at least one antenna of the phased array to provide a minima in a main radiated lobe of the phased array, such that when the phased array is moved from a first position, for detecting the RF transponder via the main radiated lobe, to a second position, where a signal from the RF transponder is minimized, a position of the RF transponder determined to be along an axis of the minima in the second position.

BRIEF DESCRIPTIONS OF THE DRAWINGS

For a better understanding of the various implementations of the invention described herein and to show more clearly how they may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings in which:

FIG. 1 depicts an antenna apparatus for determining the position of a radio-frequency (RF) transponder, according to non-limiting implementations.

FIGS. 2 and 3 depict a radial power diagram for the antenna apparatus of FIG. 1, according to non-limiting implementations.

FIG. 4 depicts the antenna apparatus of claim 1, in various positions for detecting an RFID tag, according to non-limiting implementations.

FIG. 5 depicts a method for determining the position of a radio-frequency (RF) transponder, according to non-limiting implementations.

FIGS. 6A and 6B depicts a front view and a rear cutaway view, respectively, of a handheld device apparatus for determining the position of a radio-frequency (RF) transponder, according to non-limiting implementations.

FIG. 7 depicts a schematic diagram of the handheld device of FIG. 6A, according to non-limiting implementations.

FIG. 8 depicts a perspective view of the handheld device of FIG. 6A in use in a location associated with a supply chain, according to non-limiting implementations.

FIG. 9A depicts the handheld device of FIG. 6A in an orientation for detecting an RFID tag, according to non-limiting implementations.

FIG. 9B depicts the handheld device of FIG. 6A in an orientation for determining a location of a radio-frequency (RF) transponder, according to non-limiting implementations.

FIG. 10 depicts a top view of the handheld device of FIG. 6A in use in a location associated with a supply chain, and in an orientation for determining a location of a radio-frequency (RF) transponder, according to non-limiting implementations.

FIG. 11 depicts the handheld device of FIG. 6A, providing an indication of a location of a radio-frequency (RF) transponder, according to non-limiting implementations.

FIGS. 12A and 12B depicts a front view and a rear cutaway view, respectively, of a handheld device apparatus for deter-

4

mining the position of a radio-frequency (RF) transponder, according to non-limiting implementations.

FIGS. 13 and 14 each depict a rear view of alternative implementations of the handheld device of FIG. 12A.

FIG. 15 depicts a phased array for determining a location of a radio-frequency (RF) transponder in two dimensions, according to non-limiting implementations.

FIG. 16 depicts a perspective view of the handheld device of FIG. 6A in use in a location associated with a supply chain, and in a detection position, according to non-limiting implementations.

FIG. 17 depicts a phased array for determining a location of a radio-frequency (RF) transponder in two dimensions, according to non-limiting implementations.

FIG. 18 depicts a three dimensional far field radiation pattern of the phased array of FIG. 17, according to non-limiting implementations.

FIG. 19 depicts a two dimensional cut of the far field radiation pattern of the phased array of FIG. 18, according to non-limiting implementations.

DETAILED DESCRIPTION

FIG. 1 depicts an antenna apparatus 100 comprising a phased array 101 of antennas 103A, 103B enabled to transmit and receive power at a given frequency for communicating with a radio-frequency (RF) transponder 105, phased array 101 being moveable, including but not limited to rotatable. RF transponder 105 will also be referred to hereafter as transponder 105; in specific non-limiting implementations, transponder 105 comprises an RFID (radio-frequency identification) tag, however it is appreciated that transponder 105 is not to be limited to RFID tags and that any suitable RF transponder is within the scope of present implementations; including but not limited to RF based tracking devices, ZigBee™ based tracking devices, active RFID tags, passive RFID tags, semi-active RFID tags, and the like.

Antenna apparatus 100 further comprises a phase shifter 107 for providing a phase shift to at least one antenna, for example antenna 103A of phased array 101, as will presently be explained. Antennas 103A, 103B will also hereafter be referred to collectively as antennas 103 and generically as an antenna 103. This nomenclature will be used throughout the present description, as appropriate.

It is appreciated that phased array 101 comprises at least two antennas 103. It is further appreciated that antennas 103 can be any suitable type of antenna, including but not limited to patch antennas of any suitable shape, dipole antennas and the like. In example non-limiting implementations, antennas 103 can comprise a pair of square patch antennas of any suitable size: in specific non-limiting implementations, each square patch antenna can be approximately 55 mm along each side. It is further appreciated that power radiated by each of antennas 103 can be polarized or unpolarized as desired. When polarized, the power radiated by each of antennas 103 can be linearly polarized or circularly polarized as desired. However, it is further appreciated that the centres of each of antenna's 103 are separated by approximately half of a wavelength ($\lambda/2$) associated with the given frequency.

It is further appreciated that phased array 101 can operate at any suitable frequency, or range of frequencies, for communicating with transponder 105, including but not limited to UHF (ultra-high frequency) frequencies. It is yet further appreciated that UHF frequencies can range from approximately 300 MHz to approximately 3 GHz. When transponder 105 comprises an RFID tag, a given frequency of operation can range from approximately 800 MHz to approximately

950 MHz, as RFID tags are generally understood to operate in this range, though the actual frequency can vary by standard and/or jurisdiction. For example, transponder **105** can comprise any suitable passive or active or semiactive RFID tag, including but not limited to EPC G1G2 RFID tags and/or EPC Class 1 Gen 2 RFID tags. Such commercial RFID tags presently operate at 865-868 MHz in Europe, and 902 to 928 MHz in North America, though certain vehicular RFID tags can operate in the range of 2.4-2.5 GHz. In general it is appreciated that the actual UHF frequency is not to be considered particularly limiting and that any suitable UHF frequency is within the scope of present implementations. In particular non-limiting implementations, antennas **103** are separated by a distance in a range approximately 16 to approximately 17 cm, operating at a frequency range of approximately 880 MHz to 940 MHz.

However it is yet further appreciated that the given frequency of operation is not limited to UHF frequencies and that any suitable frequency is within the scope of present implementations. For example, a given frequency of operation can include, but is not limited to microwave ranges. Indeed, a given frequency of operation can be in a range that includes approximately 300 MHz to approximately 10 GHz.

It is yet further appreciated that in some implementations, phased array **101** can operate using unpolarized RF radiation, while in other implementations phased array **101** can operate using polarized RF radiation. In implementations where phased array **101** operates using polarized RF radiation, the RF radiation can be linearly polarized, circularly polarized, or any other suitable polarization state.

Antenna apparatus **100** further comprises any suitable RF transceiver **109** for powering antennas **103**, including but limited to an RF power supply and RF receiver; hence, in present implementations, antenna apparatus **100** further comprises a power divider **111** for dividing power from RF transceiver **109** to each antenna **103**. Power divider **111** can be any suitable power divider including but not limited to a Wilkinson power divider that can achieve isolation between output ports while maintaining a matched condition on all output ports; hence the condition of power supplied to each antenna **103** is similar.

However, antenna apparatus **100** can comprise any suitable number of RF transceivers, each of which can power one or more of antennas **103**. When the number of RF transceivers is in a one-to-one relationship with the number of antennas **103**, power divider **111** can be eliminated from antenna apparatus **100**.

It is appreciated that when antenna apparatus **100** comprises, for example, two RF transceivers, the phase of each RF transceiver is coordinated to be out of phase: hence, in these implementations, a suitable phase shifter is enabled to coordinate and/or suitably shift the phase of a first RF transceiver relative to a second RF transceiver to control the phase shift there between.

In any event, in depicted implementations, it is appreciated that power from RF transceiver **109** has a given phase and that phase shifter **107** is enabled to receive power from RF transceiver **109** and shift the phase of the power before conveying the power to antenna **103A**. For example, in present implementations, phase shifter **107** shifts the phase of power from RF transceiver **109** by approximately 180°. Hence, antennas **103A**, **103B** are approximately 180° out of phase.

The effect of the phase shift is depicted in FIG. 2, which depicts a radial power diagram **200** of phased array **101**, including antennas **103**, with phase shifter **107** providing an approximately 180° phase shift to antenna **103A**; FIG. 2 also depicts the relative positions of antennas **103**. From FIG. 2, it

is appreciated that a main radiated lobe **201** of phased array **101** comprises a minima **203**. In depicted non-limiting implementations, minima **203** comprises a null. It is further appreciated that minima **203** is located approximately half way between antennas **103**. It is further appreciated that radial power diagram **200** is shown in two dimensions only, but that actual radiated power will be over three dimensions. Specifically, minima **203** will extend linearly in and out of the page, approximately mid way between antennas **103**.

In contrast, radial power diagram **200** includes a depiction of a radiation pattern **205** (i.e. the broken line) of a single antenna **103**, which is substantially uniform in all directions: in other words, there is no minimum. While not depicted, it is further appreciated that a radiation pattern of phased array **101** with phase shifter **107** disabled (e.g. turned off and/or removed from antenna apparatus **100**), is similar to radiation pattern **205**, however with slightly more power being radiated along the 0-axis between antennas **103a** and **103b**.

It is further appreciated that in depicted implementations, main radiated lobe **201** has an angle of approximately $\pm 30^\circ$; however the angle of main radiated lobe **201** can vary depending on the shape, size, and type of each antenna **103**, and can further vary with power radiated by each antenna **103**. For example, in further implementations, the angle can be as large as approximately $\pm 45^\circ$. It is appreciated that angles referred to herein are generally measured at -3 dB on a given radiation pattern, such as radiation power diagram **200**.

It is further appreciated that the device detection angle of main radiated lobe **201** increases with increasing power. For example, it is appreciated that increasing the power does not change the antenna emission pattern (e.g. the shape of the radial power diagram **200**), but that antenna emission pattern becomes stronger with increasing power, and hence the detection threshold changes. Thus, the detection angle of transponder **105** changes because the detection threshold changed.

It is further appreciated that in depicted implementations, each antenna **103** is mounted in the same plane (e.g. on a flat surface). However, in other implementations each antenna **103** need not be in the same plane; in these implementations, each antenna **103** can be at any suitable angle to one another in both X and Y directions (i.e. in a direction parallel to a longitudinal axis of phased array **101** and in a direction perpendicular to the longitudinal axis of phased array **101**). In other words, antenna **103A** can be inclined and/or declined with respect to antenna **103B** and vice versa. It is appreciated that when antennas **103** are not in the same plane, the phase shift there between could be less than 180° in order to produce minima **203**.

It is further appreciated that the angle of minima **203**, about the 0 degree axis, in depicted implementations has an angle of approximately $\pm 5^\circ$ (approximately 10° total), though again this angle can vary depending on the shape, size, and type of each antenna **103**, and can further vary with power radiated by each antenna **103**. In other implementations, the angle of minima **203** be as wide as approximately $\pm 15^\circ$. In general, it is appreciated that the angle of minima **203** decreases with increasing power. However, in some implementations, a high power with a correspondingly wide angle, can be used initially to generally locate transponder **105**, and the power can then be decreased to decrease the angle of minima **203**, to better locate transponder **105** (e.g. phased array **101** is moved at a first power to locate transponder **105** using negative logic such that transponder **105** is determined to be in first angular range, and then phased array **101** is moved at a second power less than the first power to locate transponder **105** using

negative logic, such that transponder **105** is determined to be in a second angular range that is a subset of the first angular range).

In general, the power radiated by antenna apparatus **100** can be in a range from 10-500 mW; however the power radiated by antenna apparatus **100** can be as high as approximately 2 Watts (W). However, the power output radiated by antenna apparatus **100** is not to be considered particularly limiting as it is appreciated that when transponder **105** comprises an RFID tag, the power output by an RFID system is regulated by jurisdiction: hence, the range of power can vary by jurisdiction, as can the maximum power output.

Attention is now directed to FIG. 3, which is substantially similar to FIG. 2 with like elements having like numbers, however transponder **105** is depicted at different positions **301A**, **301B** and **302**. At positions **301A**, **301B**, transponder **105** is detectable via main radiated lobe **201** using techniques known to persons of skill in the art, such as RFID techniques. For example, power emitted from main radiated lobe **201** is received at transponder **105** at a given position **301A**, **301B**, which responsively emits a given signal **303A**, **303B** detected by phased array **101**. With further reference to FIGS. 2 to 4, it is further appreciated that radial power diagram **200** includes side lobes that also comprise minima; however these minima are generally appreciated to not be as sharp or as deep as minima **203**. Furthermore the side lobes are not as intense as main radiated lobe **201**. Hence, detection of transponder **105** by side lobes and/or minima (using negative logic) of side lobes can be distinguished from detection of transponder **105** by main radiated lobe **201** and/or minima **203** using threshold values, as described in further detail below. It is appreciated that signal **303** emitted by transponder **105** can comprise data stored at transponder **105**, such as data identifying items to which transponder **105** is attached, or the like. In other words, when transponder **105** is in the angle of main radiated lobe **201** but outside the angle of minima **203**, transponder **105** is detectable.

In depicted implementations, transponder **105** is approximately parallel with phased array **101**. However, it is appreciated that the orientation of transponder **105** is not to be considered particularly limiting. While some transponders (e.g. come RFID tags) can be generally planar, which can affect whether or not a given transponder can absorb enough energy from phased array **101** to turn "on", it is appreciated that combinations of transponders and phased arrays a given transponder (e.g. using generally omnidirectional antennas) is not generally affected by orientation are within the scope of present implementations. It is further appreciated that phased array **101** can be polarized (linearly, circularly, or the like) and that such polarization can affect orientation at which transponder **105** is detected.

However, when transponder **105** is located at position **302**, i.e. within the angle of minima **203**, transponder **105** is not detectable and/or power of a signal from transponder **105** at position **302** can decrease to a minimum value (such as zero power) which is not detectable by an RF receiver associated with RF transceiver **109**.

Hence, using a negative logic principle, a position of transponder **105** can be detected. FIG. 3 also depicts outer axes **330** of minima **203**, and it is appreciated that when an RF transponder is located using a negative logic principle the RF transponder will be located along one of axes **330** and/or any axis there between.

For example, attention is now directed to FIG. 4, which depicts phased array **101** at three angles of rotation **401A**, **401B** and **402** with respect to transponder **105**, angles of rotation **401**, **402** also referred to hereafter as positions **401**,

402. It is appreciated that the underlying assumption of FIG. 4 is that the position in space of transponder **105** is fixed and that phased array **101** moves with respect to transponder **105**. Hence, FIG. 4 further depicts radial power diagram **200** of phased array **101** at each position **401**, **402**, as well as the relative position **301**, **302** of transponder **105** at each position **401**, **402**. It is furthermore appreciated that while main radiated lobe **201** and minima **203** are not labeled in FIG. 4, each are nonetheless present and depicted.

At position **401** of phased array **101**, transponder **105** is detectable by phased array **101**, as described above. However, when phased array **101** is moved from position **401** to position **402**, where a signal from transponder **105** is minimized, a position of transponder **105** is determined to be along an axis of minima **203** at position **402**. Hence, for example, as phased array **101** is moved, phased array **101** will first detect transponder **105** via main radiated lobe **201**, acquiring the data transmitted from transponder **105**, and then phased array **101** will lose signal **303** from transponder **105** as it decreases and is lost in minima **203**: it is appreciated that, using a negative logic principle (i.e. when transponder **105** is not detected after first being detected), position **302** of transponder **105** will be along an axis of minima **203**, or approximately normal to antennas **103** and/or phased array **101**. For example, transponder **105** will be along one of axes **330** or any axis there between.

It is appreciated, however, that transponder **105** can operate in one of two modes: "on" and "off". In other words, transponder **105** generally operates according to two thresholds field strengths: a first threshold of RF radiation wherein transponder **105** turns on, and a second threshold wherein transponder **105** turns off, the first threshold higher than the second threshold. In these implementations, it is appreciated that transponder **105** turns on when located off of an axis of minima **203** (i.e. transponder **105** absorbs energy from main radiated lobe **201** and/or sides lobes) such that the RF radiation reaches at transponder **105** reaches the first threshold. It is further appreciated that transponder **105** turns off when located along an axis of minima **203** such that the RF radiation falls to the second threshold. Hence, when transponder **105** turns off, no signal is detected from transponder **105** at phased array **101** and it is determined that transponder **105** is located along an axis of minima **203**.

Attention is now directed to FIG. 5 which depicts a method **500** for determining a location of an RF transponder. In order to assist in the explanation of method **500**, it will be assumed that method **500** is performed using antenna apparatus **100**. Furthermore, the following discussion of method **500** will lead to a further understanding of antenna apparatus **100** and its various components. However, it is to be understood that antenna apparatus **100** and/or method **500** can be varied, and need not work exactly as discussed herein in conjunction with each other, and that such variations are within the scope of present implementations.

At block **501**, transponder **105** is detected via main radiated lobe **201** of phased array **101** in a first position. In some implementations, phase shifter **107** can be disabled (e.g. using any suitable switch) for block **501**, such that minima **203** is removed and the main radiated lobe of phased array **101** is similar to radiation pattern **205** of FIG. 2. Alternatively, at block **501**, only one of antennas **103** can be powered, and the other of antennas **103** turned off, such that the main radiated lobe of phased array **101** is similar to radiation pattern **205** of FIG. 2.

In any event, once transponder **105** has been detected, at block **503**, a position of transponder **105** is determined. Specifically phased array **101** is moved, as depicted in FIG. 4,

such that a signal from transponder **105** is minimized and/or disappears, and the position of transponder **105** determined to be along an axis of minima **203**.

With further reference to FIGS. **2** to **4**, it is appreciated that radial power diagram **200** includes side lobes that also comprise minima; however these minima are generally appreciated to not be as sharp or as deep as minima **203**. Furthermore the side lobes are not as intense as main radiated lobe **201**. However, as described above, transponder **105** generally operates according a first threshold of RF radiation wherein transponder **105** turns on and a second threshold of RF radiation wherein transponder **105** turns off, the first threshold greater than the second threshold. Hence, in some implementations, minima in side lobes are not deep enough to cause transponder **105** to turn off. In yet other implementations, minima in side lobes can be very noisy (i.e. not as deep or as sharp as minima **203**) and hence RF radiation received by transponder **105** when located in minima in the side lobes can be very noisy, causing transponder to turn off and on rapidly. Such a noisy response can be detected by phased array **101** and a determination can be made that transponder **105** is not located along an axis of minima **203** due to the noisy response. In yet further implementations, transponder **105** being located along an axis of minima **203** vs. a minima of the side lobes can be distinguished by at least one of varying power to phased array **101** and moving phased array **101**. For example, as the minima in side lobes are not as sharp or as symmetrical as minima **203**, an increase in power of phased array **101** will cause transponder **105** to turn on when located in a minima of the side lobes, whereas transponder **105** will not turn on when located along an axis of minima **203**. Similarly, small movements of phased array **101** will cause a rapid increase of RF radiation at transponder **105** when transponder **105** is located in a minima of the side lobes; hence phased array **101** can be enabled to detect sudden changes and/or rapid changes in the signal from transponder **105** and determine that transponder **105** is located at side lobes and not along an axis of minima **203**. In yet further implementations, transponder **105** can first be detected with the phase shift at phased array **101** turned off (i.e. to turn transponder **105** on), and then with the phase shift at phased array **101** turned on to position transponder **105** in minima **203** by moving phased array **101**. Indeed, any suitable method for distinguishing minima in side lobes from minima **203** is within the scope of present implementations.

It is yet further appreciated that minima **203** is positioned in a radial axis of radial power diagram **200**, and hence a scan for RF transponders is generally performed around the radial axis: devices which incorporate a phased array similar to phased array **101**, such as hand held terminals, can be designed such that a natural rest position of such devices is with the radial axis facing forward. In these implementations, the side lobes are not generally a factor as only RF based devices that are generally in front of the phased array (i.e. along and/or proximal to the radial axis of the phased array) are detected.

Alternatively, phased array **101** can be moved from position **401A** through position **402** and further to position **401B** (or vice versa), and then back to position **402**. The detection of signal **301** starting at a maximum value, decreasing to a minimum, and then increasing again to approximately the maximum again, can indicate that transponder **105** is located approximately in front of phased array **101**, rather than off to one side.

It is appreciated that each of the methods described above can be performed using suitable electronics, such as a processor (e.g. as described below with reference to FIG. **7**), for

detecting transponder **105** and determining the location of transponder **105**, as will presently be explained. For example, specific non-limiting implementations will now be described with reference to FIGS. **6A**, **6B**, and **7** to **11**. FIGS. **6A**, **6B** and **7** depicts a front view, a rear partial cutaway view and a schematic view, respectively, of a handheld device **600**, also referred to hereafter as device **600**. It should be emphasized that the structures depicted in FIGS. **6A**, **6B**, and **7** to **11** are purely exemplary.

Handheld device **600** comprises an antenna apparatus **602**, phased array **601**, antennas **603**, a phase shifter **607**, an RF transceiver **609** and a power divider **611** similar to antenna apparatus **100**, phased array **101** and antennas **103**, phase shifter **107**, RF transceiver **109** and power divider **111** respectively. Device **600** further comprises at least one input device **622**, a display **624**, a processor **708**, non-volatile storage **712**, volatile storage **716**, and optionally an interface for communicating with a network (e.g. such that data collected from RF transponders, including but not limited to RFID tags, can be transmitted and stored remotely and/or data associated with RF transponders can be requested, or the like).

Device **600** can be any type of suitable handheld electronic device, such as the OMNII XT device manufactured by the assignee of the present invention, enabled to collect data from RF transponders, such as transponder **105**. In specific non-limiting implementations, device **600** comprises a handheld device for supply chain logistics, however in other implementations, device **600** can comprise any suitable handheld device enabled to collect data from RF transponders, including but not limited to any suitable combination of portable electronic devices, mobile computing device, portable computing devices, tablet computing devices, laptop computing devices, PDAs (personal digital assistants), cellphones, smartphones and the like. Other suitable computing devices are within the scope of present implementations.

Device **600** includes at least one input device **622**. Input device **622** is generally enabled to receive input data, and can comprise any suitable combination of input devices, including but not limited to a keyboard, a keypad, a pointing device, a mouse, a track wheel, a trackball, a touchpad, a touch screen and the like. Other suitable input devices are within the scope of present implementations.

Input from input device **622** is received at processor **708** (which can be implemented as a plurality of processors and/or as one or more central processing units (CPUs)). Processor **708** is configured to communicate with a non-volatile storage unit **712** (e.g. Erasable Electronic Programmable Read Only Memory ("EEPROM"), Flash Memory) and a volatile storage unit **716** (e.g. random access memory ("RAM")). Programming instructions that implement the functional teachings of device **600** as described herein are typically maintained, persistently, in non-volatile storage unit **712** and used by processor **708** which makes appropriate utilization of volatile storage unit **716** during the execution of such programming instructions. Those skilled in the art will now recognize that non-volatile storage unit **712** and volatile storage unit **716** are examples of non-transitory computer readable media that can store programming instructions executable on processor **708**. It is further appreciated that each of non-volatile storage unit **712** and volatile storage unit **716** are also examples of memory units and/or memory modules.

In particular, non-volatile storage unit **712** can store an application **736** which can be processed by processor **708**, application **736** for controlling antenna apparatus **602** and determine a location of an RF based tracking device.

Processor **708** can also be configured to render data at a display. Display **624** comprises any suitable one of or com-

11

combination of CRT (cathode ray tube) and/or flat panel displays (e.g. LCD (liquid crystal display), plasma, OLED (organic light emitting diode), capacitive or resistive touchscreens, and the like).

Processor 708 can also connect to a network interface 728, which can be implemented in some implementations as one or more radios configured to communicate with a remote computing device (not depicted), such as a logistics server, via a communications network (not depicted). In general, it will be understood that interface 728 is configured to correspond with a network architecture that is used to implement a link with a communication network.

In some implementations, device 600 further comprises at least one position device 750 for determining a position and/or orientation and/or movement of device 600. For example, position device 600 can comprise any suitable combination of an accelerometer, a gyroscopic device, a magnetometer and/or a GPS (global positioning system) device, and the like.

In some implementations, device 600 can also comprise an indicator device 760, controllable by processor 708 to indicate a location of an RF transponder. For example, indicator device 760 can include, but is not limited to, a speaker, a light (such as an LED or the like), a haptic device (such as a vibratory motor or the like), a laser pointer, a combination thereof, or the like.

It is yet further appreciated that, while not depicted, device 600, including RF transceiver 609, is generally powered by a battery.

It should be understood that in general a wide variety of configurations for device 600 are contemplated.

With reference to FIG. 6B, it is appreciated that antennas 103 as depicted are vertically aligned and facing towards the rear of device 600 such that device 600 can be held by a user with display 624 visible thereto, and moved to detect and determine location of RF transponders, similar to transponder 105, as will hereafter be explained.

For example, as depicted in FIG. 8, device 600 can be used in a location associated with a supply chain, such as a warehouse, to locate RF based tracking transponders 105A, 805B, attached to items such as pallets 801A, 801B, respectively. It is appreciated that device 600 is located approximately half way between pallets 801. In present implementations, it will be assumed that each transponder 105 comprised data identifying a respective pallet 801, and specifically the text "PALLET A" is stored at device 805A, and "PALLET B" is stored at transponder 105B. However it is appreciated that any suitable data can be stored at transponders 105, including alphanumeric identifiers that can be cross-referenced with data stored at a remote logistics server.

In any event, as depicted in FIG. 9A, device 600 can detect transponders 105 (e.g. via the main radiated lobe of phased array 601, similar to main radiated lobe 201) and retrieve data stored thereupon upon display the retrieved data at display 624 (i.e. "PALLET A", "PALLET B"). An option to locate transponders 105A, 805B can then be provided in the form of virtual buttons "Yes" and "No". If "No" is actuated (e.g. via a pointing device and/or a touch screen device or the like), device 600 proceeds to any suitable process for supply chain logistics or the like. However, if "Yes" is actuated (e.g. via a pointing device and/or a touch screen device or the like), an indication (not depicted) to re-orient device sideways is provided at display 624 such that device 600 is oriented as in FIG. 9B. For example, text such as "Turn Device sideways to locate RFID tags" can be provided at display 624 to prompt a user to re-orient device 600.

Further, instructions to "Rotate Device Left and Right", or the like, can be provided at display 624 when device 600 is in

12

the orientation of FIG. 6. Further, position device 750 can determine that device 600 has been re-oriented and cause processor 708 to correspondingly re-orient text at display 624. It is further appreciated that device 600 could be re-oriented 90° clockwise or counter clockwise from the orientation of FIG. 9B, as desired.

With reference to FIG. 6B and with further reference FIGS. 2-4, it is appreciated that when device 600 is oriented as in FIG. 9A, antennas 603 are aligned vertically and when device 600 is oriented as in FIG. 9B, antennas 603 are oriented horizontally (as in FIGS. 2-4). Hence, in FIG. 9B, minima 203 extends vertically from device 600, and moving device 600 left and right will cause minima 203 to sweep through signals from transponders 105.

For example, FIG. 10 depicts a top view of a location with device 600 re-oriented as in FIG. 9B and turned towards transponder 105B. Arrow 1000 is indicative of device 600 being moved left and right. In any event, FIG. 10 also depicts radial power diagram 200 of phased array 601 (i.e. the radial power diagram of phased array 601 is the same, in this implementation, as the radial power diagram of phased array 101), and it is appreciated that minima 203 is pointed towards transponder 105A, while part of main radiated lobe 201 is pointed towards transponder 105B. Hence, as the signal from transponder 105A will have fallen to minimum, and indeed nulled out, processor 708 via processing of application 736, can determine that transponder 105A is in the direction of an axis of minima 203. In response, processor can cause an indication of the location of transponder 105A to be provided at device 600, by one or more of: rendering a visual indicator at display 624 to indicate the location, controlling a speaker (e.g. indicator device 760) to provide an aural indicator to indicate the location, controlling a light (e.g. indicator device 760) to indicate the location, controlling a haptic device (e.g. indicator device 760) to indicate the location and, controlling a laser device (e.g. indicator device 760) to indicate the location. In other words, when the location of transponder 105A is determined, an icon and/or text can be provided at display 624 (as in FIG. 11, described below), a sound can be displayed at a speaker, a light can turn on and/or change color, device 600 can vibrate and/or a laser pointer built into the rear of device 600 (on the same side as antennas 805B) can point perpendicularly outwards from device 600. For example, attention is directed to FIG. 16, which is substantially similar to FIG. 8 with like elements having like numbers. However, in FIG. 16, device 600 has been moved such that transponder 105A is detected, when transponder 105A is detected, device 600 emits a laser beam 1600 perpendicularly and hence in a direction of transponder 105A.

Indeed, any suitable method of indicating the location of transponder 105A is within the scope of present implementations. A specific non-limiting implementation is depicted in FIG. 11, in which display 624 is controlled to provide text "Device is now facing 'PALLET A'", i.e. an indication of location and an identifier of transponder 105A, such as data retrieved from transponder 105A.

In yet further implementations, when device 600 comprises a position device 600 (i.e. any suitable combination of an accelerometer, a gyroscopic device, a magnetometer and/or a GPS device and the like) data from position device 600 can be captured (e.g. received, acquired or the like at processor 708) and stored in association with an identifier of the located RF transponder (e.g. transponder 105A and/or transponder 105B), for example at non-volatile storage device 712 and/or in any suitable database. Indeed, such data can be acquired by device 600 and transmitted and/or provided to a remote database for storage. Such associated data could be

13

used at a later time to provide an indication of the location of a located RFID tag; hence, others could be directed to the located RFID transponder at a latter time.

Similarly, when device **600** is moved towards transponder **105B**, display **624** can be controlled to provide text “Device is now facing “PALLET B””. Any suitable method of returning to a mode for reading RF transponders without determining location is within the scope of present implementations, such as actuation of a virtual button “DONE”, and/or re-orienting device **600** to the orientation of FIG. **9A**.

In some implementations, phase shifter **607** can be disabled when not in the mode for determining the location of an RF transponder such that the radial power diagram is substantially uniform when detecting and reading RF transponders; similarly, phase shifter **607** can be enabled when in the mode for determining the location of an RF transponder. Enabling and disabling phase shifter **607** can occur automatically; alternatively, enabling and disabling phase shifter **607** can occur manually, for example, via input device **622** and/or virtual buttons rendered at display **624**. In any event enabling/disabling phase shifter **607** has the effect of turning minima **203** on and off (e.g. switching between radiation pattern **205** and radial power diagram **200** comprising main radiation lobe **201** and minima **203**).

Alternatively, one of antennas **603** and phase shifter **607** can be turned off and/or disabled when not in the mode for determining the location of an RF transponder such that the radial power diagram is substantially uniform when detecting and reading RF transponders; similarly, both antennas **603** and phase shifter **607** can be turned on enabled when in the mode for determining the location of an RF transponder. Turning one of antennas **603** on and off when enabling and disabling phase shifter **607** can occur automatically; alternatively, turning one of antennas **603** on and off when enabling and disabling phase shifter **607** can occur manually, for example, via input device **622** and/or virtual buttons rendered at display **624**. In any event, turning one of antennas **603** on and off, when enabling/disabling phase shifter **607**, has the effect of turning minima **203** on and off, as well as saving power in the mode for detecting RF transponders (e.g. switching between radiation pattern **205** and radial power diagram **200** comprising main radiation lobe **201** and minima **203**).

It is yet further appreciated that in some implementations, device **600** can comprise an input device for adjusting the power of phased array **601**, for example a button or knob at input device **622** and/or a virtual button or knob provided at display **624**. It is appreciated that adjusting the power of phased array **601** can have tradeoffs. For example, increasing power can increase the distance that an RF transponder can be detected, as well as increasing the sharpness of minima **203** (e.g. decreasing the angular spread of minima **203**); however increasing power can also shorten battery life.

Attention is now directed to FIGS. **12A** and **12B**, which depict front and rear cutaway views, respectively of a handheld device **600a** for determining location of an RF transponder. Device **600a** is similar to device **600**, with like elements having like numbers however with an “a” appended thereto. Device **600a** differs from device **600** in that phased array **601a** extends horizontally across device **600a**, whereas phased array **601** extends vertically down device **600**. Hence, reorienting device **600a** when determining location of an RF transponder is obviated.

Attention is now directed to FIG. **13** which depicts a rear view of a handheld device **600b** for determining location of an RF transponder. Device **600b** is similar to device **600a**, with like elements having like numbers however with a “b”

14

appended thereto rather than an “a”. Device **600b** differs from device **600a** in that phased array **601b** moves between a horizontal in-use position (as with device **600a**) and a vertical storage position. Movement between the two positions is indicated by arrow **1301**, and can occur automatically via any suitable motor (such as a servo-motor) and/or manually. When manual, device **600b** can provide an indication to move phased array **601b** to the suitable orientation, for example instructions provided at a display device (not depicted). Phased array **601b** can be spring loaded and deployed upon actuation of a suitable button or the like.

Attention is now directed to FIG. **14** which depicts a rear view of a handheld device **600c** for determining location of an RF transponder. Device **600c** is similar to device **600b**, with like elements having like numbers however with a “c” appended thereto rather than a “b”. Device **600c** differs from device **600b** in that the phased array is deployed on two arms **601c-1** and **601c-2**, each of which swing between a horizontal in-use position and a vertical storage position. Movement between the two positions is indicated by arrows **1401**, and can occur automatically via any suitable motor (such as a servo-motor) and/or manually. When manual, device **600c** can provide an indication of moving arms **601c-1**, **601c-2** to the suitable orientation, for example via instructions provided at a display device (not depicted). Arms **601c-1** and **601c-2** can be spring loaded and deployed upon actuation of a suitable button or the like.

Attention is now directed to FIG. **15** which depicts a phased array **1501** that comprises a first pair of antennas **1503A-1**, **1503B-1**, and a second pair of antennas **1503A-2**, **1503B-2**, each pair similar to antennas **103A**, **103B**, with one set of diagonally opposed antennas (e.g. **1503A-1** and **1503A-2**) being approximately 180° out of phase with the other set of diagonally opposed antennas (e.g. **1503B-1** and **1503B-2**) such that a radial power diagram comprises a first minima **1513A** disposed vertically between (for example) **1503A-1**, **1503B-1** and a second minima **1513B** disposed horizontally between (for example) **1503A-1**, **1503B-2**, second minima **1513B** being perpendicular to first minima **1513A**. It is appreciated that the intersection point of minima **1513A** and **1513B** comprises a point where an RF transponder cannot be detected hence, using a negative logic principle, when a signal from an RF transponder falls to a minimum in both the horizontal and vertical directions, the RF transponder is located in a line that extends perpendicularly from the intersection point. Hence the RF transponder can be located in at least two spatial dimensions. Alternatively, and RF transponder can be located using one of minima **1513**, in one spatial direction.

It is further appreciated that an antenna apparatus for detecting and locating RF transponders can comprise a phased array of any suitable number antennas, each of which are provided with a suitable phase shift relative to the other antennas to provide at least one minima in the main radiated lobe and/or to focus a main lobe to create a minima. Hence, while phased array **101** comprises two antennas **103** and phased array **1501** comprises four antennas **1503**, other implementations of antennas apparatus can comprise any suitable number of antennas to provide at least one minima. It is furthermore appreciated, that the any suitable number of antennas can be odd or even in number; hence, while pairs of antennas have been described herein, antennas of a phased arrays in other implementations need not be arranged in pairs.

Hence, in contrast to other antennas apparatus for detecting RF transponders, antennas apparatus of present implementations enable a position of an RF transponder to be located.

15

It is yet further appreciated that while movement of antenna apparatus and/or phased arrays described herein has been described as a manual process, in yet other implementations, movement of antenna apparatus and/or phased arrays described herein can be automatic. For example, antenna apparatus and/or phased arrays described herein can be mounted to a rotational jig, for example a 2-axis jig or a 3-axis jig, which can be controlled in a feedback loop to move an antennas apparatus and/or a phased array to minimize a signal from an RF transponder, and thereby determine the location of the RF transponder. Such apparatus can be used in supply chain locations to determine locations of RF transponders, and/or in any other implementations where an RF transponder is to be located.

It is yet further appreciated that while heretofore, movement of antenna apparatus and/or phased arrays has been described as either a manual and/or mechanical process, yet further implementations comprise electronic control of antenna apparatus and/or phased arrays: in other words, the phase can be controlled electronically, creating an automatic electronic movement (including but not limited to electronic rotated), without any manual or mechanical movement.

While antennas described herein have been patch antennas, present implementations are not limited to patch antennas but can include any suitable antenna. For example, attention is directed to FIG. 17 which depicts a layout of a phased array 1701 comprising two dipole antennas 1705A, 1705B, each comprising a printed circuit of copper traces; it is appreciated that the copper traces are not fully linear, and the lines are folded to address space limitations and for impedance matching. In specific non-limiting implementations, antennas 1705 operate at a frequency of 866 MHz and are separated by a distance of 17.32 cm (i.e. half of a wavelength of 34.64 cm at 866 MHz), with one of antennas 1705A, 1705B being 180° out of phase with the other of antennas 1705A, 1705B. A three-dimensional far field radiation pattern 1800 of phased array 1701 is depicted in FIG. 18, and an associated two-dimensional cut 1900 of pattern 1800 is depicted in FIG. 19. From FIGS. 18 and 19 it is appreciated that pattern 1800 of phased array 1701 comprises a zero emission point along a radial axis and hence phased array 1701 can be used to detect RF transponders using negative logic as described above. Indeed, it is appreciated that any suitable phased array of any suitable type of antennas can be used to detect RF transponders.

Furthermore, as will now be appreciated, phase shifter 107, 607, can comprise any suitable phase shifter means for introducing a phase shift between antennas 103, 603, 1503, 1705 in order to produce a minima there between in a radiation pattern, including but not limited to electronic apparatus, mechanical apparatus (e.g. tilting etc. of antennas 103, 603, 1503, 1705) and the like. It is yet further appreciated that phase shifter 107, 607 can be a separate device as depicted herein, and/or can alternatively be integrated with phased array 101, 601, 1501, 1701.

Those skilled in the art will appreciate that in some implementations, the functionality of antenna apparatus 100 and device 600 can be implemented using pre-programmed hardware or firmware elements (e.g., application specific integrated circuits (ASICs), electrically erasable programmable read-only memories (EEPROMs), etc.), or other related components. In other implementations, the functionality of antenna apparatus 100 and device 600 can be achieved using a computing apparatus that has access to a code memory (not shown) which stores computer-readable program code for operation of the computing apparatus. The computer-readable program code could be stored on a computer readable

16

storage medium which is fixed, tangible and readable directly by these components, (e.g., removable diskette, CD-ROM, ROM, fixed disk, USB drive). Furthermore, it is appreciated that the computer-readable program can be stored as a computer program product comprising a computer usable medium. Further, a persistent storage device can comprise the computer readable program code. It is yet further appreciated that the computer-readable program code and/or computer usable medium can comprise a non-transitory computer-readable program code and/or non-transitory computer usable medium. Alternatively, the computer-readable program code could be stored remotely but transmittable to these components via a modem or other interface device connected to a network (including, without limitation, the Internet) over a transmission medium. The transmission medium can be either a non-mobile medium (e.g., optical and/or digital and/or analog communications lines) or a mobile medium (e.g., microwave, infrared, free-space optical or other transmission schemes) or a combination thereof.

Persons skilled in the art will appreciate that there are yet more alternative implementations and modifications possible, and that the above examples are only illustrations of one or more implementations. The scope, therefore, is only to be limited by the claims appended hereto.

What is claimed is:

1. An antenna apparatus comprising:

a phased array of antennas configured to transmit and receive power at a given frequency and configured to communicate with a radio frequency (RF) transponder, the phased array being movable;

a phase shifter configured to provide a phase shift to at least one antenna of the phased array to provide a minimum adjacent a main radiated lobe of the phased array; and

a processor configured to detect transmission from the RF transponder via the main radiated lobe at a first position wherein when the phased array is moved from the first position to a second position, at the second position where a signal from the RF transponder is minimized, the processor is configured to determine a position of the RF transponder to be:

along an axis of the minimum in the second position based on a rate of change in the signal from the RF transponder during a movement of the phased array; or

removed from the axis of the minimum in the second position based on the rate of change in the signal from the RF transponder during the movement of the phased array,

wherein the processor is further configured to determine when the position of the RF transponder is along the axis of the minimum, and in response, providing an indication of the position of the RF transponder, wherein providing the indication of the position of the RF transponder comprises at least one of:

rendering a visual indicator at a display to indicate the position;

controlling a speaker to provide an aural indicator to indicate the position;

controlling a light to indicate the position;

controlling a haptic device to indicate the position; and

controlling a laser device to indicate the position.

2. The antenna apparatus of claim 1, wherein the minimum comprises a null and no response is received from the RF transponder when the RF transponder is located along the axis of the minimum in the second position.

3. The antenna apparatus of claim 1, wherein the phase shift is 180°.

17

4. The antenna apparatus of claim 3, wherein the phased array comprises a first pair of antennas, wherein the centers thereof are separated by half of a wavelength associated with the given frequency.

5. The antenna apparatus of claim 3, wherein the phased array further comprises a second pair of antennas laterally displaced from the first pair, one antenna of the second pair configured to be out of phase with the remaining antenna of the second pair providing a second minimum in the main radiated lobe perpendicular to the minimum such that the RF transponder can be located in at least two spatial dimensions.

6. The antenna apparatus of claim 1, further comprising: at least one RF transceiver for powering the phased array.

7. The antenna apparatus of claim 6, wherein the at least one RF transceiver is common to all antennas of the phased array, and further comprising a power splitter for splitting power from the at least one RF transceiver to all the antennas of the phased array.

8. The antennas apparatus of claim 1, wherein the phase shifter is configured to be enabled and disabled such that the minimum can be turned on and off, and such that the RF transponder can be detected in the first position with the phase shifter disabled and the minimum removed, and the position of the RF transponder determined in the second position with the phase shifter enabled and the minimum turned on.

9. The antenna apparatus of claim 1, wherein, for detecting the RF transponder in the first position, a given antenna of the phased array is enabled to be on while remaining antennas are enabled to be off in the first position, thereby turning the minimum off, and in the second position, the remaining antennas are further enabled to be on, with the at least one antenna phase shifted, thereby turning the minimum on.

10. The antenna apparatus of claim 1, further comprising a handheld device for providing data received in the signal from the RF transponder and providing an indication of the position of the RF transponder at a display, the phased array integrated with the handheld device.

11. The antenna apparatus of claim 1, where the given frequency is in at least one of a range of 300 MHz and 100 GHz, and a range of 800 MHz to 950 MHz.

12. A method comprising:

detecting, by a processor of a handheld device, transmission from an RF transponder via a main radiated lobe of a phased array of antennas in a first position, the phased array is configured to transmit and receive power at a given UHF (ultra high frequency) frequency and configured to communicate with the RF transponder, the phased array being moveable;

determining, by the processor, a position of the RF transponder when the phased array is moved to a second position where a signal from the RF transponder is minimized, wherein at least one antenna of the phased array phase is shifted using a phase shifter to provide a minimum in the main radiated lobe and the position of the RF transponder is determined to be:

along an axis of the minimum in the second position based on a rate of change in the signal from the RF transponder during a movement of the phased array; or

removed from the axis of the minimum in the second position based on the rate of change in the signal from the RF transponder during the movement of the phased array; and

providing an indication of a position of the RF transponder, wherein providing the indication of the position of the RF transponder comprises at least one of:

18

rendering visual indicator at a display to indicate the position;

controlling a speaker to provide an aural indicator to indicate the position;

controlling a light to indicate the position;

controlling a haptic device to indicate the position; and

controlling a laser device to indicate the position.

13. The method of claim 12, wherein the phase shifter is configured to be enabled and disabled such that the minimum can be turned on and off, the method further comprising detecting the RF transponder in the first position with the phase shifter disabled and the minimum removed, and determining the position of the RF transponder in the second position with the phase shifter enabled and the minimum turned on.

14. The method of claim 12, wherein, for detecting the RF transponder in the first position, a given antenna of the phased array is enabled to be on while remaining antennas are enabled to be off in the first position, thereby turning the minimum off, and in the second position, the remaining antennas are further enabled to be on, with the at least one antenna phase shifted, thereby turning the minimum on.

15. A computing device comprising:

a phased array of antennas configured to transmit and receive power at a given frequency and configured to communicate with a radio frequency (RF)-based tracking device, the phased array being movable;

a phase shifter configured to provide a phase shift to at least one antenna of the phased array to provide a minimum in a main radiated lobe of the phased array; and

a processing unit configured to:

detect the RF-based tracking device via the main radiated lobe of the phased array of antennas in a first position;

determine a position of the RF-based tracking device when the phased array is moved to a second position where a signal from the RF-based tracking device is minimized, wherein the position of the RF-based tracking device is determined to be:

along an axis of the minimum in the second position based on a rate of change in the signal from the RF-based tracking device during a movement of the phased array; or

removed from the axis of the minimum in the second position based on the rate of change in the signal from the RF-based tracking device during the movement of the phased array; and

provide an indication of a position of the RF transponder, wherein providing the indication of the position of the RF transponder comprises at least one of:

rendering visual indicator at a display to indicate the position;

controlling a speaker to provide an aural indicator to indicate the position;

controlling a light to indicate the position;

controlling a haptic device to indicate the position; and

controlling a laser device to indicate the position.

16. A computer program product, comprising a non-transitory computer usable medium having a computer readable program code adapted to be executed to implement a method comprising:

operating a phased array of antennas configured to transmit and receive power at a given frequency and configured to communicate with a radio frequency (RF) transponder, the phased array being movable;

operating a phase shifter configured to provide a phase shift
to at least one antenna of the phased array to provide a
minimum in a main radiated lobe of the phased array;
and
operating a processor configured to detect transmission 5
from the RF transponder via the main radiated lobe at a
first position such that when the phased array is moved
from the first position to a second position where a signal
from the RF transponder is minimized, the processor is
configured to determine a position of the RF transponder 10
to be:
along an axis of the minimum in the second position
based on a rate of change in the signal from the RF
transponder during a movement of the phased array;
or 15
removed from the axis of the minimum in the second
position based on the rate of change in the signal from
the RF transponder during the movement of the
phased array; and
providing an indication of a position of the RF transponder, 20
wherein providing the indication of the position of the
RF transponder comprises at least one of:
rendering visual indicator at a display to indicate the
position;
controlling a speaker to provide an aural indicator to 25
indicate the position;
controlling a light to indicate the position;
controlling a haptic device to indicate the position; and
controlling a laser device to indicate the position.

* * * * *

30